ECONOMIC BOTANY

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The Taxonomy, Harvesting, Processing and Utilization of Eucalyptus Trees in Australia

Among the 500 species known in Australia, about 60 have attained economic importance, being used primarily for building purposes, secondarily as sources of pulp, tannin and oils.

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Classification and Occurrence

The kinds of eucalypt in Australia are more numerous than the days in the year, and they are distributed over nine-tenths of Australian forest land. It is interesting to reflect that before the year 1686, when Dampier may have seen them during his landing on the Australian coast but without realising their identity, eucalypts were unknown to any but the primitive Australian aborigines who made from them spears, boomerangs and rough canoes. David Nelson collected the first eucalypt for science in Tasmania in 1777 during the third voyage of the explorer Captain James Cook. His material examined in the herbarium at Kew, England, was named in 1788 "*Eucalyptus obliqua*" by the French botanist l'Heretier. The generic name was derived from the Greek eu (well) and kalypto (I cover) in recognition of the fact that eucalyptus bud caps cover the developing flowers more remarkably than do those of other trees.

The botany of the eucalypts was studied systematically by F. von Mueller and G. Bentham, followed later by J. H. Maiden, R. T. Baker, H. G. Smith and W. F. Blakely. They have described and separated species and endeavoured to divide the genus into sections with a view to associating species closely allied and to simplifying identification. Classification in the herbarium and recognition in the forest of the different species are difficult. The ranges of many species overlap so that mixtures are generally found in eucalypt forests. Von Mueller placed emphasis on the bark as a means of primary division and used three classes of anthers in the flower when developing keys for naming 100 species. Bentham made five classes and named 143 species. Maiden produced six classes, and Blakely further sub-divided these into eight sections. The sections, distinguished by the anthers, are subdivided into series and sub-series based on size; habit; bark; juvenile, intermediate and mature leaves; oil; buds; fruits; seed and timber. Baker and Smith paid special attention to veining in the leaves and showed that oils present in various species are closely related to the type of veining. The early descriptions covered what are now regarded as some compound units, and from these several other species have been split. In splitting species the principle has been followed of giving specific rank to cases where small observable differences exist. Some of the small differences may be revealed in wood structure. Blakely, in his "Key to the Eucalypts", has endeavoured to bring groups together in right relation in sub-series. By 1934, 500 species and 138 varieties of the genus *Eucalyptus* had been recorded. Since then more than 25

new species have been added, and further additions are anticipated when all regions have been fully explored botanically. Five species are recorded for New Guinea, one of which, *E. deglupta*, extends to the Philippine Islands; several species are found in Timor.

to a previously known timber. The work of the botanists eventually proved that several different names had been given to trees of the same botanical identity, but by that time the different names had become established in various localities. It was a difficult task to remove

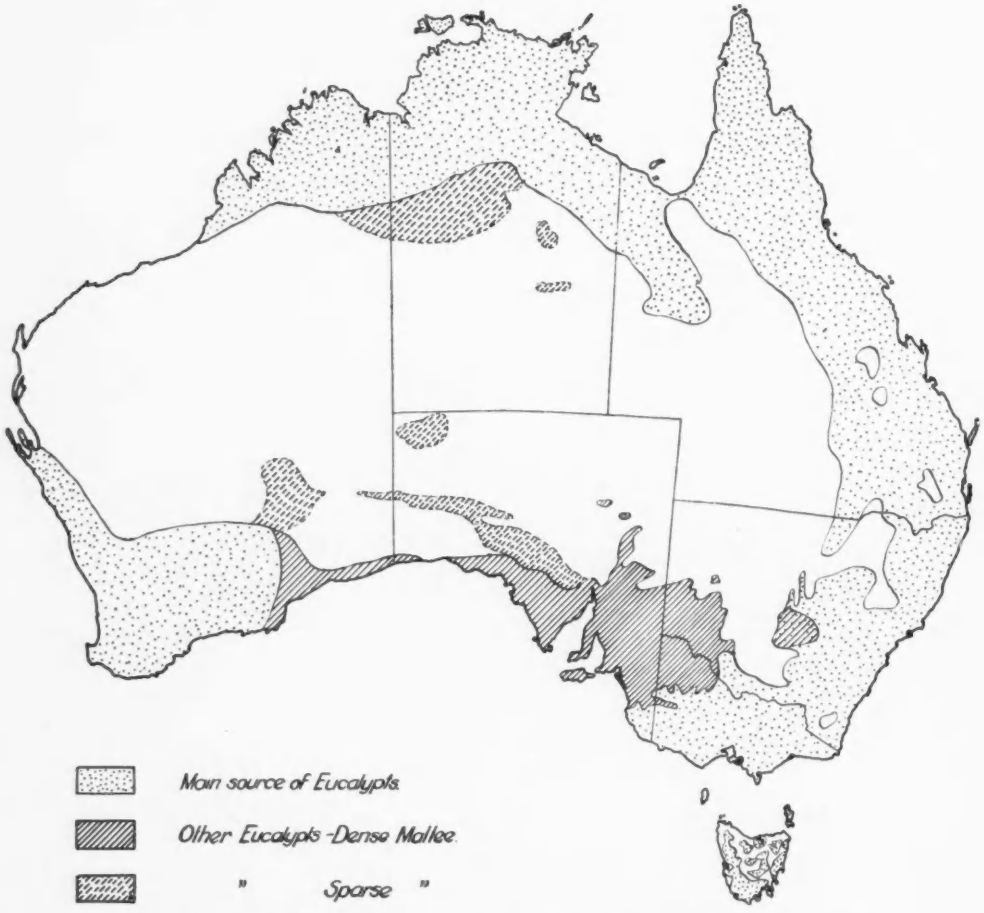


FIG. 1. Map showing distribution of the principal forest areas in Australia.

Unfortunately the early colonists began to apply common names to the newly found timbers of Australia long before systematic botanists had completed their reviews, and the common names were sometimes descriptive of the tree, the characteristic colour or texture of the bark, the colour of the wood, or purported to indicate some resemblance

the contradictions and to introduce names proposed for standardisation on a national basis into districts where the local names had been in use for many years, even though the residents supported standardisation sympathetically in principle. A special effort has been made to overcome the confusion by preparing a list entitled "Nomenclature of

Australian Timbers". This was published by the Standards Association of Australia as A.S. No. 0.2 in 1940. It has been widely adopted since that date in official specifications; scientific, technical and trade papers; addresses; correspondence and everyday discussions on timber, so that its influence is now widespread. Its acceptance has done much to improve the situation, and representations are being made to widen its scope and thereby reduce to a minimum the contradictions and inconsistencies in the names of Australian timbers.

The character of the bark has proved a great aid to bushmen, foresters and the public generally in recognising many forest trees, and has had an important influence on the naming and consequently on the selection and marketing of eucalypts in Australia. A little experience is sufficient to ensure familiarity with stringybarks, ironbarks, gums (or smooth barks) and barks of other types, but it is necessary to be prepared for a number of exceptions and to take into account other diagnostic features before deciding the identity. A rough classification, based on bark and forms commonly observed in the forest, is as follows:

	No. of Species
Mallees and mallee-like trees ...	123
Gums and blackbutts	120
Boxes	60
Stringybarks	44
Bloodwoods	43
Peppermints	29
Ironbarks	23
Mahoganies	13
Other scaly barks	33

In addition, names such as "ash", "oak" and "mahogany" have been borrowed from abroad, and for others, distinctive aboriginal names have been retained.

FIG. 2. *Eucalyptus regnans.* Height: 326 feet; girth: 28 feet, 7 inches, six feet from the ground. Mt. Baw Baw, Victoria.

The mallees are small trees or shrubs of little importance industrially; many other species are rare; some are found only in inaccessible areas; some are too small in size for commercial utilization; and in others the quality is unsuitable for economic conversion. Only about 60 species have attained economic importance—the names and descriptions of these are given in Table 3, pp. 126–129.

Eucalyptus is a remarkable genus in many ways. It includes some of the heaviest, hardest and most durable woods, such as the ironbarks with air-dried densities up to 71 pounds per cubic foot. The lightest in weight is *E. gigantea,* 39 pounds per cubic foot. In size they range from stunted forms of mallees, eight feet tall, to the tallest hardwood in the world. *Eucalyptus regnans* has been authentically measured to 326 feet but is reputed to be taller, and in the Cumberland Valley, Victoria, the average height of 27 trees of this species on one reserved acre is 266 feet. The Western Australian *E. diversicolor* is also very tall; the best specimen measured near Pemberton, Western Australia, was 278 feet tall. Other species in virgin forests attain massive trunks whose butt diameters at times exceed 20 feet. The tendency of the largest trees to flare at the butt makes precise measurement difficult. Diameters in excess of ten feet were by no means uncommon in the original stands of *E. regnans, E. obliqua, E. marginata, E. diversicolor, E. pilularis* and other big trees. The sawmilling industry has to provide facilities for transporting and breaking down heavy logs. Although diameters exceeding ten feet are now exceptional, there are sufficient trees exceeding six feet to necessitate the provision of heavy equipment.

The volume in some areas is particularly heavy, records of 250,000 super feet[1] log measure per acre having been exceeded. The average is impracticable to determine, but generally 20,000 super feet log measure would be considered a good yield from an acre in areas worked by the sawmilling industry. Giant individual trees have been found to contain as much as 63,780 super feet of merchantable volume.

Some forests are worked on clear felling systems, but the greatest volume is obtained from forests in which systems of tree selection are applied. In some regions sustained yield has been attained. The nature of the forests and the silvicultural requirements of the species govern the methods used. Eucalypts under 18-inch butt diameter are seldom felled for sawmilling unless from salvage considerations or during forest improvement work.

In Australia, where they originate, the eucalypts lend character to the landscape, give shade for man and beasts, some food for native fauna, and produce for commerce posts, poles, piles and timber for railway sleepers, boats, bridges, carriages, furniture, houses, cases, crates, pulp, paper and fuel. Other products from the genus include honey, medicines, oils and perfumes. Eucalypts are among the world's important hardwoods and the loveliest flowering trees. Seeds of the genus have been taken as far afield as North Africa, Spain, Portugal, France, Black Sea coasts of Russia, Abyssinia and South America. They were planted to rid the Pontine marshes near Rome of malaria. They were taken to South Africa to produce badly needed timber, and to California where the success of their establishment and growth has led many Californians to regard them as indigenous.

The distribution of main forests in Australia is shown in Fig. 1. The area indicated embraces, besides forests, the best agricultural land which has been alienated for that purpose; moreover, many parts near the limits of tree growth in the interior support only sparse formations which can not be regarded as

[1] 1 super foot = $\frac{1}{1\frac{1}{2}}$ cubic foot.

FIG. 3. *Eucalyptus pilularis*. Manning River, State Forest, N. S. W.

commercial forests. The net forest area is accordingly much less than it seems. At present 24,500,000 acres have been dedicated as permanent forest reserves and placed under control of forestry authorities in the respective States. The net forest reserve is less than one per cent of the area of Australia.

Not all of the forests are managed in the forestry sense, and under current conditions some areas are inaccessible and do not contribute supplies of timber. Other areas held privately yield some supplies. The total harvest includes saw logs, peeler logs and logs for hewing; round wood, including piles, poles, posts, house stumps and other items used in the round without conversion; pulpwood in round and split form; firewood; and wood for distillation. The quantities of these respective classes of wood procured in the year ended June, 1945, are shown in Table 1.

Eucalypts make up the bulk of the figures for hardwood, it being estimated that they contribute 2,995 million super feet to the quantity and £13,400,000 to the value shown in Table 1.

TABLE 1

OUTPUT OF AUSTRALIAN GROWN WOOD—1945

	Quantities in millions of super feet[1]; the equivalent of round timber true measure under bark						Value, million £ Australian
	(1) Saw logs	(2) Round-wood	(3) Pulp-wood	(4) Fire-wood	(5) Wood for distil-lation	Total	
Softwoods							
From state forests	304	...	6	...	...	310	2.1
From private forests ..	63	...	1	...	...	64	0.4
Total	367	...	7	...	...	374	2.5
Hardwoods							
From state forests	1,110	60	54	664	44	1,932	9.6
From private forests ..	461	53	74	792	133	1,513	5.8
Total	1,571	113	128	1,456	177	3,445	15.4
Grand Total	1,938	113	135	1,456	177	3,819	...
Value in million £ Australian	11.6	0.9	0.4	4.6	0.4	....	17.9

[1] One super-foot $= \frac{1}{12}$ cubic foot.

Logging

Logging methods follow the usual steps of felling, cross-cutting, snigging or bunching, loading and transporting to the mill. The variations in topography and types of forest in different parts of Australia do not allow the logging practices to conform with one pattern. In localities specially favoured by easy access, snigging may be eliminated and loading carried out at the stump, or alternatively sawmills may be located close enough to the trees to allow logs to be snigged directly to the mill skids, thus obviating the need for other log transportation.

Logging operations in Australia are continued generally throughout the year. Snow may cause cessation of logging in limited areas in the southeastern highlands for a few weeks, and torrential rain

FIG. 4. Felling a eucalypt tree, front scarf completed with single-bitted axe, back cut being commenced with hand cross-cut saw, staging used to allow fellers to work above the flare of the butt.

may halt extraction operations in North Queensland for two or three months. Elsewhere interruptions due to weather are generally of short duration.

None of the eucalypts is capable of floating when freshly felled; hence, even if suitable waterways existed, eucalypt logs could not be flumed or rafted. Logging in Australia is essentially a land operation, the only logs transported by water being carried by barges or ocean-going vessels.

The tools used for felling are the single-bitted axe with curved handle and the cross-cut saw. Since many species have a pronounced flare in the butt, it is often found necessary to erect a staging for felling operations. In recent years power-driven portable chain saws have entered the field of felling and cross-cutting, and their use seems likely to extend, particularly if units more robustly constructed can be made available. Power-driven drag saws are frequently used for cross-cutting.

Due to the weight of the eucalypts and the large dimensions that they have attained in primeval forests, it is impossible to log many species in tree lengths. In such lengths their weight would exceed the capacity of available haulage machinery, and cross-cutting practice has developed with a view to limiting weights to be snigged, loaded and hauled. Short-length logging accordingly predominates in most big tree areas, and this practice leads to short log sawmilling in dependent sawmills.

Ground skidding is the most common method of primary extraction. Animals originally used for this work have been largely superseded by tractors. The latter have also largely replaced steam driven winches that were formerly operated in forest areas where the topography is steep.

Some attempts have been made to use skyline logging methods, but these have not been permanently established. Highlead has been operated with apparent success in steep country carrying heavy volumes per acre. Flying fox transportation rigging has also been successfully used in certain areas where the terrain is too difficult for conventional access by road or rail. A boom spar or crotch line for loading may sometimes be rigged for operation in conjunction with these overhead systems, but by far the most common arrangement for loading is a set of skids on sloping ground to which logs may be snigged and then cross-hauled by means of a hook, rope and winch, and rolled or simply jacked on to the bunks of the transport vehicle.

There is a need and constantly recurring demand for tractors of 120 H.P. rating and over. For snigging or skidding with tractors, wheeled or crawler track arches are in service in some areas, but dragging directly on the ground is the most common practice.

Advances in automotive equipment, particularly the development of diesel-powered tractors and trucks and the general improvement in roading, have tended to extend road haulage in place of rail haulage; nevertheless the railways continue to provide an important link in the transport chain.

Sawmills in the forest outnumber those in townships or on the seaboard. Some recently developed policies favour the location of new sawmills in country towns instead of in forests where the problem of manning them is serious because families do not wish to live in localities remote from amenities and where educational facilities are lacking for the young generation.

Sawn Timber

Sawing. Eucalypt logs have characteristics which are responsible for a number of important differences in sawing technique compared with that predominating in North America and Europe. Defective heart is common in eucalypts, and logs of many species, which may show no evidence of incipient or ad-

FIG. 5. Boom loader in *Eucalyptus regnans* forest.

vanced decay in the heart have at least a brittle core which must be eliminated from the products of conversion; consequently sawing methods based on cutting from bark to bark are almost impracticable.

Eucalypts as a class are self-pruning and at an early age free themselves from branchlets so that the bole of the trees gains in diameter practically free from knots. When logs are opened up during conversion, distinct bands of high grade timber are not found to be concentrated in the outer zone of the cross section, as in coniferous timbers, but rather the defects that are most characteristic of the genus, namely, gum veins, gum pockets and insect traces occur indiscriminately in the section. Interior quality can seldom be assessed with accuracy from external appearances, and each log presents somewhat individual problems in conversion and requires a certain amount of exploratory opening before the optimum placing of cuts for highest recovery of the products can be decided. The usual practice is to break down the log initially into slabs and flitches as large as possible, consistent with facility in handling and revelation of interior quality, and to produce the finished products by secondary sawing of the slabs and flitches on a machine usually called a breast bench.

For breaking down, the majority of eucalypt sawmills are equipped with twin circular saws. The twin circulars are served by a log carriage, and in small sawmills this is of the flat table-top type; in medium sized sawmills it may be fitted with knees and set-works. There is only one installation of powered dogs known in an Australian forest sawmill carriage, and powered setworks are rare. The aids for loading logs on to the carriage are usually a winch with rope plus hook and canthook or crowbar. There are only three log turners of the Simonson type in the whole industry. Most of the drives for the log carriage consist of an endless rope over a winding drum driven most commonly by friction. A few small steam feeds are installed, an occasional twin engine steam feed, and only two direct acting shotgun feeds are known to be operated.

In localities where logs are large in size, and the daily intake small in volume, reciprocating frame saws have found favour for breaking down. These have often been constructed by local millwrights, and their low capital cost and slow rate of operation are consistent with the needs of the small sawmill. They are used for opening up the large logs, halving or quartering these more or less according to size.

Relatively little sawing to dimensions is carried out with Australian breaking-down saws or head saws. The primary object in their operation is to produce pieces of sizes and weights suitable for handling over the production benches to which their work is related. Occasionally they produce a flitch of a predetermined thickness, but the preparatory cuts that they make are usually neglected by the sawyers at the breast benches.

To obtain best recovery and greatest proportion of high grades, repeated turning of the pieces is necessary during sawing. Mass production methods, such as those adopted in America or the most common standardised practices of Europe, would be undesirably wasteful with Australian eucalypts. The main production bench comprises typically a circular saw mounted on a table provided with horizontal rollers driven by power in forward feeding and reversing directions to facilitate handling of the pieces over the bench top against a gauge until sawn out into various marketable sections. Such a bench could be expected reasonably to produce 7,500 super feet daily.

Due to seasoning characteristics the eucalypts are usually sawn practically into their final dimensions at the sawmill centre. Production of flitches for re-

FIG. 6. Poles and piles of *Eucalyptus crebra*.

sawing is exceptional and practised only where special arrangements can be promptly implemented to transfer sections quickly from the sawmill to the resawing plant. The drying of multiple thicknesses is prolonged and may be accompanied by serious degrade caused by uneven shrinkage, internal checking and, in some species, collapse.

Some species need to be sawn with the wider face as nearly parallel with a radius as possible, and to that end a technique of quartersawing has been developed and has been practised in the southeastern States for several decades.

Australian sawmills are generally small units, and, with the exception of a few in Western Australia cutting *E. marginata* and *E. diversicolor*, the annual sawn output of a eucalypt sawmill seldom exceeds five million super feet. Throughout Australia there are reported to be approximately 1,700 sawmills, and their sawn output, including non-eucalypts, is approximately 950 million super feet annually, so that the average output is slightly more than half a million super feet per annum per mill. Sawmilling is limited to this scale largely by the relatively small volume of standing timber per acre and the general faultiness of available logs.

The main products of sawmilling are boards for seasoning and subsequent remanufacture into flooring, weatherboards or furniture; also building scantling, structural timbers and case timber. In periods when the overall production approaches 950 million super feet per annum, eucalypts would contribute approximately 650 million, and the main subdivisions of this production would be: constructional timber—530 million super feet; manufacturing timber—80 million super feet; case timber—40 million super feet.

Grading. The timber trade in Australia recognizes several broad divisions of quality in sawn timber, and the grade descriptions of select, standard (or merchantable) and common (sometimes called case grade) are widely adopted for pricing purposes. In many instances the grades are not described in precise terms and are rather loosely interpreted. There are definite steps being taken, however, to promote sound grading practices. Grading rules have been prepared for flooring and other milled products, joinery, boards sawn for subsequent re-manufacture, and structural timber. Several specifications have been issued under the aegis of the Standards Association of Australia, and work is proceeding to widen the scope of the standards so that they will cover all principal items of production.

Typical grading rules are those for sawn and hewn structural timber issued as Australian Standard (E) No. 0.54.

Some of the forestry authorities have organised timber inspection branches within their departments, and grading services may be rendered on request of buyer or seller and an inspection certificate may be issued. Some of the larger government and semi-government organisations have inspectors attached to their buying departments.

Seasoning. The eucalypts tend to be refractory timbers to season. More attention is needed during their seasoning period than is commonly given to coniferous timbers. The initial moisture content of eucalypts is usually high, their rate of drying relatively slow, and unless drying of the surfaces is carefully regulated during the earliest stages, some case-hardening may occur and adversely affect the final condition of the timber. Fewer liberties as regards dimensions of stack, thickness and spacing of strips and ventilation around the stacks can be taken with eucalypts than with timbers that are easily dried.

Air-seasoning may be successfully accomplished, and guides to sound practice are available for most of the species.

Kiln-drying has been developed to a state of high efficiency. Schedules for

kiln-drying of many eucalypts have been established by research and commercial trials. In the majority of cases it has been found that a combination of air-drying and kiln-drying is the most economical procedure, and this is commonly adopted in the Australian timber industry. There are approximately 600 kilns installed in Australia with a charge capacity of 3,000,000 super feet of all timbers, out of which approximately two-thirds is used for eucalypts. The most favoured size for general use is a kiln nine feet wide, 11 feet high and 32 or 42 feet long, accommodating a charge about five feet, six inches wide, about six feet high and 30 or 40 feet long, respectively. The capacity of kilns of these dimensions, when filled with timber one inch thick, stacked with strips three-quarter inch thick, is approximately 6,000 super feet for the 32-foot kiln, or 8,000 super feet for the 42-foot kiln. The compartment kiln has proved to be most satisfactory for the kiln drying of eucalypt species, and the most efficient is the cross-shaft internal fan type.

A phenomenon known as " collapse ", occurring principally in *E. regnans, E. obliqua* and *E. gigantea,* but also in other species, is removable by a reconditioning treatment consisting of steaming with saturated steam for several hours and re-drying. This treatment is practically the standard practice in the plants drying these species and is carried out in reconditioners built specially for the purpose.

FIG. 7. Loading *Eucalyptus saligna* and *Eucalyptus microcorys* from a log landing by means of a jack.

Several methods are used in handling timber to be seasoned, the aim common to all methods being to reduce re-handling of individual boards to a minimum

once a stack has been built. Provision is generally made for moving a timber stack into the air-drying yard, then into the kiln, then into the reconditioning chamber if necessary, and then into a storage shed as one unit. Frequently this is done by means of a lifting truck working in conjunction with a transfer truck. For this system the yard is laid out with skids, built to a uniform height on level ground and arranged to permit a lifting truck to be moved underneath the timber stack supported on the skids; and supports for the stack are provided at the same height inside the kiln. Alternatively an overhead gantry crane may be worked in conjunction with a lifting truck and a transfer truck. In some installations timber is stacked on the trucks which are left in the kiln while the timber dries. The introduction of the lifting truck has resulted in an outstanding reduction in the cost of handling throughout the various stages of seasoning. Few installations are large enough to justify a fleet of straddle carriers and fork lift trucks, but the adaptation of these to Australian conditions is being investigated.

Remanufacturing. Approximately 90 percent of sawn and hewn eucalypt timber is utilized in Australia in the form, and substantially in the sizes, in which it leaves the sawmill or centre of primary manufacture. There are no large-scale re-sawing industries for eucalypts, such as commonly established for the re-sawing of coniferous timbers. In some parts of the country seasoning plants are set up to receive sawn timber of dressing quality from several sawmills, and some have installed machines for running the timber after seasoning into various milled products, particularly flooring. Many of the larger timber merchants and retail distributors establish their own facilities for machining timber to pattern into flooring, weatherboards, lining, mouldings, *etc.*, and employ joiners to produce window sashes and frames, door jambs, doors, staircases and other builders' fitments. The principal activities in remanufacturing, therefore, comprise milling to pattern, dressing to finished sizes or carrying out jointing, fabrication or other numerous operations connected with the manufacture of the woods into end products.

Round Wood

Eucalypt trees attain forms suitable for poles and piles, and they may often require little in the way of limbing or other preparation to fit them for service. Species of highest resistance to fungi and termites are preferred; they include *E. crebra, E. hemiphloia, E. paniculata, E. propinqua, E. punctata, E. redunca* var. *elata, E. siderophloia* and *E. sideroxylon.* Other species ranked high in durability and also in great demand for poles and piles include *E. corymbosa, E. marginata, E. melliodora, E. microcorys, E. rostrata* and *E. leucoxylon.*

Owing to the high durability of these eucalypts and the difficulties of impregnating most of the species satisfactorily with preservatives, the headway made in Australia in preservation practices has not been spectacular. Butt treatments are applied prior to installation, and the charring and spraying technique is common in maintenance activities. In recent years demands for eucalypts of the highest durability for posts, poles and piles have exceeded supply, and greater attention is being given to the possibilities of increasing by preservation treatment the life of the species of lower durability rating.

Bark is removed with hand tools, and often sapwood is removed at the same time to comply with the specifications of some electrical transmission authorities. The majority of poles are used in the round, but for high voltage transmission, pole lengths may approach 70 feet, and dressing is sometimes specified. For this purpose an octagonal shape is attained usually with hand tools. The practice of de-sapping has been in vogue for many years and would be open to question if

FIG. 8 (*Upper*). Bridge constructed in eucalypt timbers.
FIG. 9 (*Lower*). Ironbark log and various tools used for hewing into sleepers.

preservation practices were more advanced. Experimental treatments have demonstrated the ease with which sapwood may be penetrated by preservatives. On a number of sites poles and posts have been set up in treated and untreated condition to demonstrate the service life of different species treated in various ways and exposed to various hazards. It is hoped that these tests will lead to better appreciation of the merits of treating unsapped round timber and verify the promise shown by treated species of low inherent durability.

It is estimated that approximately 3,000,000 poles are in service throughout Australia, and that annual requirements approximate 125,000 poles. The conditions of exposure are extremely variable.

Wooden piles are common in Australian maritime structures. Here the hazards vary with temperature, salinity and tidal range between wide limits, and the value of different species is affected accordingly. The timber most favoured is *Syncarpia laurifolia,* and the eucalypts in greatest demand are *E. paniculata* and other ironbarks, *E. hemiphloia, E. punctata, E. corymbosa* and *E. marginata.* A universally effective preventative against marine borer attack applicable to the eucalypts has not been found. Many piles are installed without protection; others may be sheathed with metal. Bandages and composite coatings of several formulations have been tried, and also a floating collar retaining creosote against the pile in the most vulnerable place.

A considerable volume of wood is used in round form for fencing and house stumps, and also for mining purposes.

Hewn Timber

A considerable industry was built up in the early phases of Australian development to supply timber in hewn form for bridges, wharves, railway sleepers, cask staves, palings and various minor items. In the decade ended 1930 the hewn output exceeded 100,000,000 super feet per annum, but the industry has subsequently declined in favour of sawmilling, the present output of hewn timber being less than 49,000,000 super feet annually, in which most is railway sleepers.

The eucalypts contributing most to hewn production are *E. marginata, E. redunca, E. hemiphloia, E. punctata, E. paniculata, E. crebra, E. rostrata, E. tereticornis, E. polyanthemos* and *E. corymbosa.*

The tools for this industry are hand types including the axe, crosscut saw, wedge, maul and broad axe. For cask staves and palings, *E. regnans, E. obliqua* and similar timbers are in demand, but with the continued depletion of supplies of fissile specimens, splitting is waning and experts with a riving knife are few.

Veneer and Plywood

The Australian veneer and plywood industry owes its founding and early development largely to the availability of *Araucaria* species. Only when supplies of the araucarias had been depleted and become unequal to the demands of the industry did the eucalypts receive attention. At the present time the eucalypts contribute approximately 11,000,000 super feet in the total intake of 44,000,000 super feet per annum of peeler logs. The principal eucalypts peeled are *E. diversicolor, E. gigantea, E. regnans, E. marginata* and *E. maculata.*

Although veneer of commercial quality is produced from these species, certain technical difficulties have been encountered arising out of the propensity of these eucalypts to check during peeling, clipping and drying. Research to overcome some of the troubles is being carried out.

Slicing has been found to produce veneers of highest quality which are easier to handle through other stages of manufacture.

The principal product of the industry is three-ply of 3/16 inch finished thick-

FIG. 10 (*Upper*). Firewood produced as a silvicultural operation in forest of *Eucalyptus sideroxylon*.

FIG. 11 (*Lower*). Cask staves and palings being split from *Eucalyptus regnans*.

ness in sheets six feet by three feet, but a range of other thicknesses, numbers of plies and sizes of sheets are produced as well as veneered panels. The eucalypts have not as yet produced as high a percentage of face quality veneers as desired, but when that quality has been obtained decorative finish has resulted.

Pulp and Paper

Manufacturing processes have been developed elsewhere in the world to produce various grades of paper from soft-

FIG. 12. Eucalypt logs at Australian sawmill showing pipe and defective heart prevalent in many species.

woods. There was very little need and very few attempts up to 1915 to manufacture paper from hardwoods, and the little that was known of the behaviour of hardwoods, when subjected to the more or less standard methods of pulp preparation, did not allow a favourable view to be taken of the possibilities of manufacturing pulp or paper from the eucalypts. About 1918 the Australian Commonwealth Government financed research into the problems of pulping eucalypts, and the outcome of experimentation carried on for some ten years was the determination of conditions required for the successful production of mechanical and chemical pulps from various eucalypts. The most promising timbers appeared to be the light weight, light coloured eucalypts of Victoria and Tasmania, and after many years of consideration of the commercial aspects of the manufacturing of paper from these timbers, it was decided about 1936 that economic factors were favourable for pulp and paper production in Australia.

The first pulp mill in Australia to utilize eucalypt timber was a pilot plant with a capacity of 3,000 tons of pulp air-dry basis per annum. This was established at Maryvale, Victoria, in January, 1937. The main plant at the same locality, with capacity of 27,000 tons of pulp per annum, commenced operations in October, 1939, using the sulphate process for digesting eucalypts, mainly *E. regnans, E. obliqua, E. gigantea, E. sieberiana* and associated species. The pulp was run into wrapping paper in an adjacent mill, and also shipped to New South Wales for wrapping paper produc-

Fig. 13 (*Upper*). Eucalyptus railway sleepers and eucalyptus trees alongside a railway.
Fig. 14 (*Lower*). A eucalyptus-using paper mill in Tasmania.

tion. A proportion of long-fibered softwood pulp imported from overseas was used to make up the required furnish.

In August, 1938, a mill started production of paper at Burnie, Tasmania, and after running for a few months on imported pulp, brought its own pulp mill into operation for pulping hardwoods, principally *E. gigantea, E. obliqua* and similar species. Pulp is produced at this mill by the soda process, and the caustic soda necessary for cooking, and the chlorine necessary for bleaching the pulp are produced in an electrolytic plant located alongside the mill. Papers produced include a wide range of high class printing, writing, drawing, duplicating and blotting papers.

The second mill in Tasmania, and the third in Australia, commenced production of newsprint at Boyer on the Derwent River, near Hobart in February, 1941. Groundwood pulp is produced from *E. regnans* principally, with small percentages of *E. obliqua and E. gigantea,* and to this is added a proportion of long-fibered imported chemical pulp.

The current rate of usage of eucalypt pulpwood by these three pulping plants is approximately 110,000,000 super feet annually. Plans for extension of each factory are being implemented, and it appears that annual requirements will exceed 230,000,000 super feet in a few years.

Supplies of pulpwood are obtained under current practices in various forms. The major quantity consists of small roundwood or split wood mainly in four-foot and six-foot lengths. In Victoria this is largely procured from forest areas devastated by fire in 1939, and from thinnings and from sawmill waste. Long logs below sawing quality are also purchased by the paper company and converted in their sawmill into pulpwood billets, while timber of building and remanufacturing quality is recovered for sale to the timber trade. In northern Tasmania supply to date has been maintained with round timber or split timber four feet long and approximately nine inches in maximum cross dimension, procured by selective felling operations. Plans are in hand to mechanise forest operations and to process the forest run of logs through barking, sawing and chipping plant, which will integrate sawn timber production with chipping requirements. The newsprint billets in southern Tasmania are produced for grinding in seven-inch by seven-inch by four-foot size from the forest run of logs in a sawmill equipped with head-saw, edger and slasher, and some timber for building purposes is produced concurrently.

The current rate of production of this industry is 125,000 tons of wrapping paper and boards, 18,000 tons of fine writing and printing paper and 33,000 tons of newsprint per annum.

Building Boards

Production of hard pressed wood-fibered building boards by the explosion process commenced in Australia in 1938. Its wood requirements are covered principally with eucalypts including *E. pilularis, E. eugenioides, E. acmenioides, E. corymbosa, E. maculata* and *E. resinifera.* The current rate of usage is 15,000,000 super feet per annum, but the industry is growing. The extension of the first plant and the development of others that will use alternative fibrating methods will increase the wood requirements in the near future to approximately 30,000,000 super feet annually. A second plant using mechanically disintegrated wood has recently commenced operation, and a third is in course of construction. The list of species utilized will be extended, and *E. gigantea, E. regnans* and *E. obliqua* will be added.

Tanning Materials

Many species of *Eucalyptus* and other genera contain varying proportions of tannin, chiefly in the bark but also in the wood and twigs. The bark of *E. astrin-*

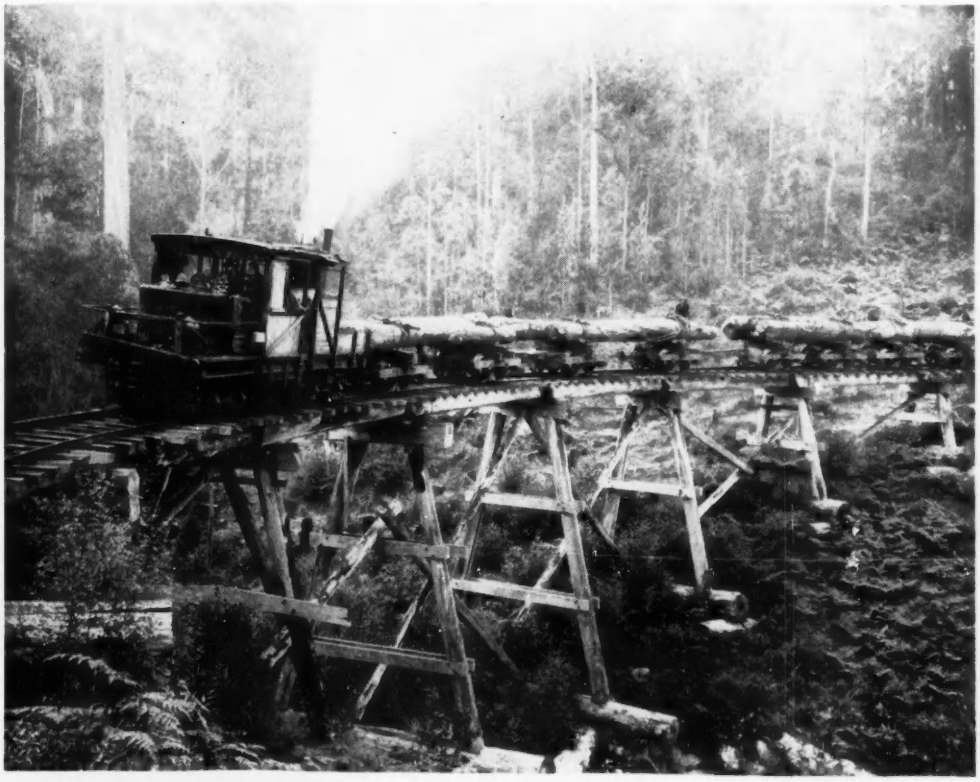


FIG. 15 (*Upper*). Transporting logs on railway in eucalypt forest.
FIG. 16 (*Lower*). Hauling logs by tractor near Lismore, N. S. W.

gens in Western Australia contains from 41 to 57 per cent tannin, and this species produces tanning bark at the rate of 1,450 tons yearly, chiefly for export to European and other countries where it is used for production of tannin extract, and a little for use when blended with wattle bark and other tanning materials in the production of leather in Australia. Barks of other mallets (*E. falcata* and *E. gardneri*) and white mallee (*E. erythomena*), each of which contains over 30 per cent of tannin, and species such as *E. campaspe, E. cladocalyx, E. pallidifolia, E. platypus* and *E. spathulata*, each of which contains between 25 and 30 per cent; and other species found to contain between 20 and 25 per cent, have not been regarded as available in commercial quantities.

An important industry was founded in 1935 in Western Australia to produce tannin extract from wandoo (*E. redunca* var. *elata*). For this purpose the whole tree is taken, including bark, trunk and timber, down to six inches in diameter at the smallest end. The material is used in the green state and is broken down in heavy duty rasping machines which cut it transversely into chips and finer particles. These are fed into autoclaves, and the tannin constituents are leached out with water by means of a counter-current press leaching system of extraction. The wet liquors are concentrated in triple effect evaporators and then fed into single stage finishers where they are concentrated to 18 or 20 percent moisture content. Approximately 65,000 tons of wandoo are utilized annually in these manufacturing activities, and the product is marketed under the name of "myrtan" in Australia and overseas.

The production of an extract from the bark of *E. diversicolor*, which is reported to contain between 11 and 20 percent tannin, and which is available in large quantities at karri sawmills, has been receiving consideration, and it is hoped that an industry may be developed to use it at an early date.

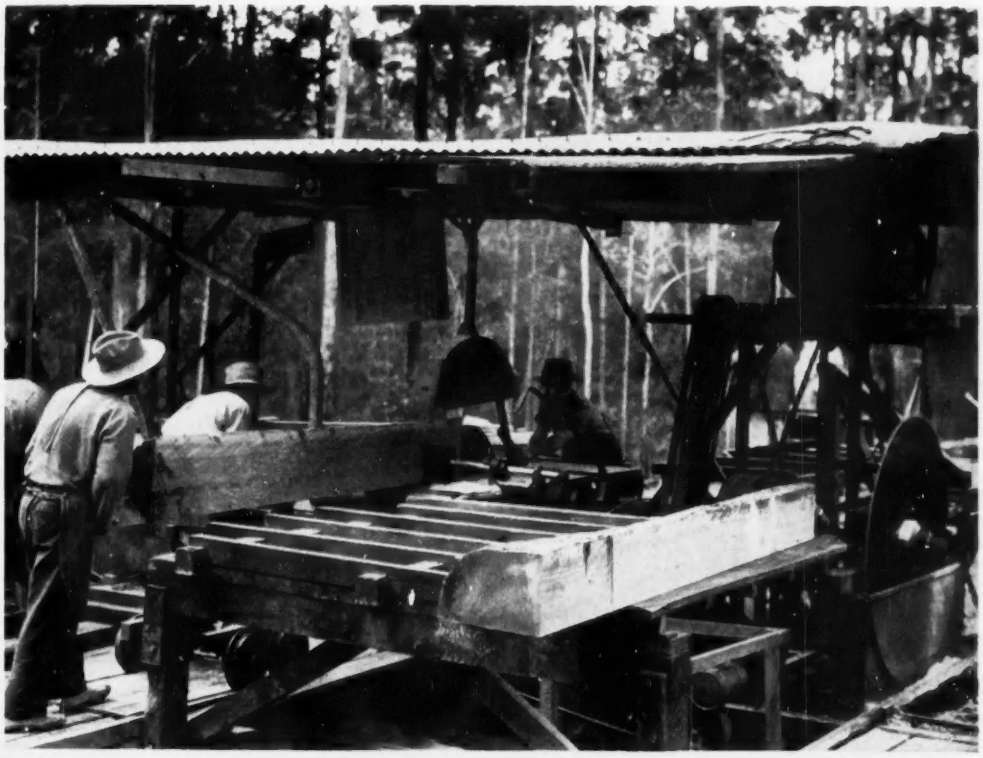
Various ironbarks, including *E. crebra, E. paniculata, E. siderophloia* and *E. sideroxylon*, which contain from seven to 30 percent tannins in the bark, and from three to six percent in the wood, and *E. rostrata*, which contains eight to 16 percent in the bark, two to 14 percent in the wood and five to 11 percent in the twigs and leaves, may be worth assessing as commercial prospects.

Chemical Wood

Chemical industries in Australia, other than pulping and tanning, do not use eucalypts to a marked extent. During World War I a wood-distillation plant was set up in Victoria and for several years produced charcoal, alcohol, acetone and acetate of lime from *E. regnans, E. obliqua* and associated species. Economic factors brought about the closure of the works soon after 1920.

During World War II the curtailment of supplies of liquid fuel for internal combustion engines led to the development of producer gas attachments for trucks and cars. Over 5,000 units were fitted to automotive vehicles engaged in essential transport, and charcoal supplies had to be organised accordingly. At peak demand, wood was being converted to charcoal at the rate of 83 million super feet per annum. The charcoal was produced principally in portable type charcoal kilns without recovery of volatiles. A great number of different eucalypts were carbonised or burnt, those specially favoured being *E. rostrata, E. paniculata, E. sideroxylon* and other ironbarks, *E. marginata, E. redunca* var. *elata* and *E. tereticornis*. The industry declined as soon as liquid fuel supplies again became available.

In the post-war period a wood-distillation plant has been brought into operation at Wundowie, W. A., as part of a project for producing charcoal iron from local deposits of an iron ore. The timber section of the plant is designed to produce per annum 45,500 tons of wood blocks for distillation, 10,000 tons of



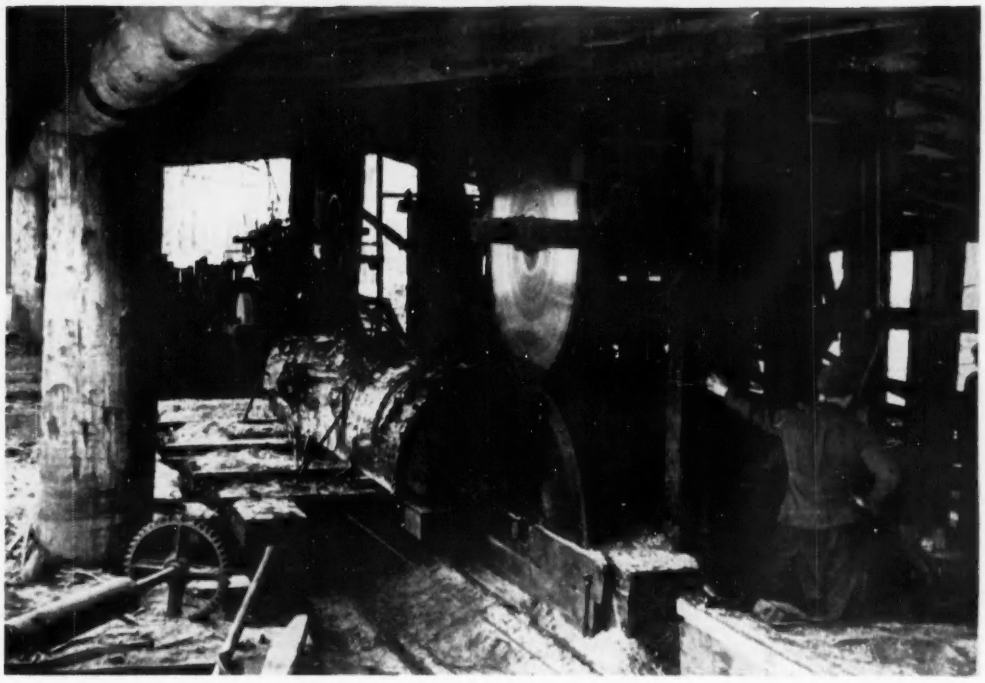


FIG. 17 (*Upper*). Breast bench in small eucalypt sawmill.

FIG. 18 (*Lower*). Twin circular breaking-down saws and table top carriage commonly used in eucalypt sawmills.

boiler wood, and approximately two million super feet of sawn timber. The distillation plant comprises a 60-cord per day carbonisation section and a refinery to recover methanol and acetic acid from the pyroligneous acid. The species principally distilled are *E. marginata, E. calophylla* and *E. redunca* var. *elata.* They are pre-dried in the form of blocks over 48 hours to between 20 and 25 percent moisture content by means of flue gases, then retorted for 24 hours in retorts heated by blast furnace gas, and the resulting charcoal is cooled for 48 hours in sealed chambers before being transferred to storage bins above the blast furnace. Charcoal is fed into the furnace with iron ore, limestone and magnesite and is consumed at the rate of one to one and a quarter tons per ton of pig iron produced. The production is small at present, but the plant is furnishing operating data on which the prospects of large scale production will be assessed.

Firewood

Many eucalypt species are in demand for firewood. Those most highly regarded are the ironbarks, grey box, other members of the box group, red gum, jarrah and the mallees. The last named are much sought after in the form of roots, since they burn steadily, giving off much heat and leaving very little ash. The other species are procured wherever possible from ring-barked or fallen trees, and when these are not available, felling or ringbarking may be advance operations. Major transportation is undertaken in six-foot or eight-foot lengths.

Domestic fuel is the principal item in demand, and for its satisfaction wood is usually docked into 12-inch or 14-inch lengths for delivery to householders. A portion is split into final sections for handling on to the fire. A ready market exists for sawmill dockings.

Industrial fuel is also an important requirement, particularly in rural areas. Pumping plants for water supply in Western Australia and for irrigation areas in the Eastern States, power plants in country towns, bakeries, laundries, mines, *etc.*, are large users of firewood.

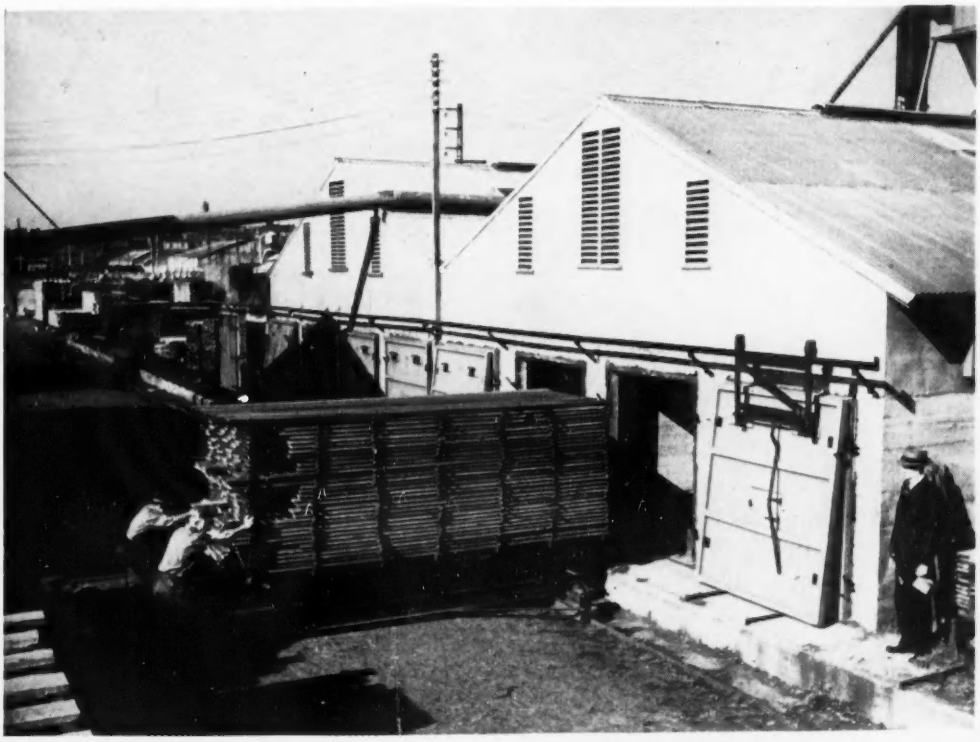
For firewood-getting power-driven saws are being used in increasing numbers. Chain saws are being brought into use for felling and cross-cutting; powered drag saws have been operated for cross-cutting for many years; and a small portable firewood bench is gaining in popularity. The approximate quantity used per annum is 1,456 million super feet.

Eucalyptus Oils

The annual production of oils from the leaves of eucalypt species is approximately 230,000 gallons valued at £A252,000. Out of this about 40,000 gallons are used in Australia for industrial purposes, and 10,000 gallons for medicinal purposes, the rest, comprising 80,000 gallons of industrial oils and 100,000 gallons of medicinal oils, being exported.

The *Eucalyptus* oils most frequently used in commerce are:

	Content in Leaves	Principal Constituent
Medicinal Oils		
E. polybractea	33%	Cineol
E. sideroxylon	20%	Cineol
E. leucoxylon	20%	Cineol
E. australiana, *E. dives*	20%	Cineol
E. elaeophora, *E. cneorifolia*, *E. viridis*, *E. dumosa*	7%	Cineol
Industrial Oils		
E. dives	....	Piperitone and phellandrene
E. phellandra	....	Phellandrene and cineol
E. numerosa	....	Phellandrene, piperitol and piperitone
Perfumery Oils		
E. macarthuri	....	Geranyl acetate, geraniol and eudesmol
E. citriodora	....	Citronellal



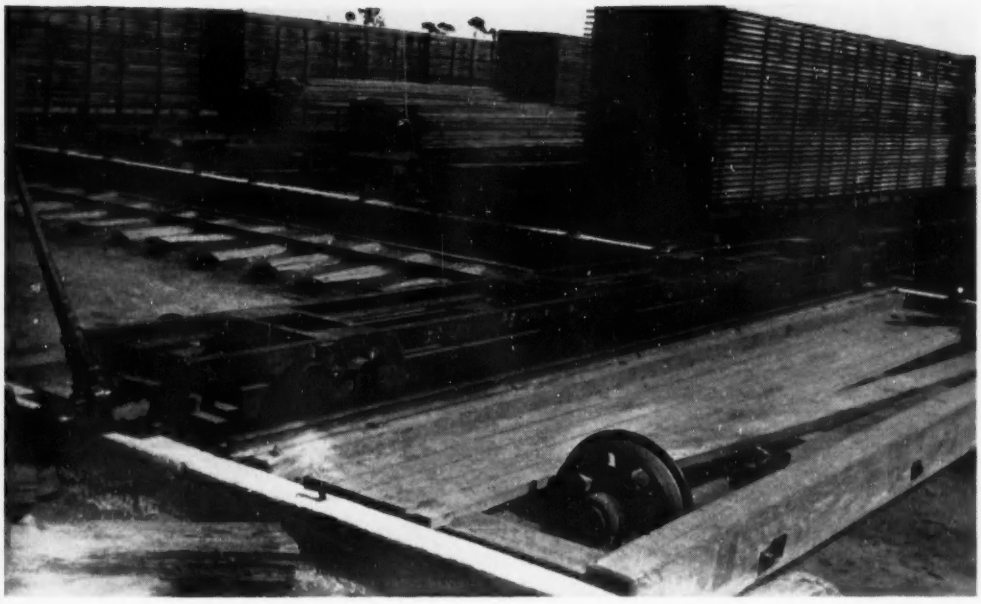


FIG. 19 (*Upper*). Drying kiln internal fan compartment type used for seasoning eucalypt timbers in Australia.

FIG. 20 (*Lower*). Lifting truck and transfer truck in an air-seasoning yard.

Eucalyptus oils are refined by redistillation before sale, with the exception of oils from *E. dives*. The first runnings, consisting of volatile aldehydes and some terpenes, as well as the final residues, find use in industry. Some of the principal constituents and their uses are:

a). Volatile aldehydes used in various preparations, such as disinfectants and sheep dips.

b). Pinene and other terpenes used in the manufacture of certain blended turpentines.

c). Cineol, the principal constituent of medicinal eucalyptus oil, used in pharmacy, confectionery and clothes cleaning to a limited extent.

d). Phellandrene, a by-product in the separation of piperitone from *E. dives* and allied species, used in association with piperitone and other constituents as a blended eucalyptus oil for mineral flotations.

e). Terpineol, separated from the high-boiling fractions of *E. australiana* and *E. dives* (var. C), the perfumery constituent of hyacinth odour.

f). Eudesmol, the principal sesquiterpene alcohol of eucalyptus oils, a very satisfactory fixative for perfumes required for industrial purposes.

g). Eudesmyl acetate, prepared by acetylating eudesmol, used as a wartime substitute for oil of Bergamot and its constituents.

h). Piperitone (commercial), assaying 90% to 95% ketone, the raw material for the manufacture of synthetic thymol and menthol.

Honey Flora

The eucalypts are important to the bee-keepers in Australia, and an industry with production valued at approximately £460,000 annually is based on the flowering habits of eucalypts and other forest trees. The industry is distributed throughout the country. The relative honey-producing merits of the various species have not as yet been accurately determined.

Honey derived from *E. melliodora* is the best liked and best known, being pale straw colour, very dense and aromatic, with a pronounced flavour. *E. hemiphloia* and the ironbarks, *E. crebra*, *E. paniculata* and *E. sideroxylon*, are nearly as good, and *E. leucoxylon*, *E. rostrata* and *E. stellulata* are ranked highly.

Properties and Uses of Eucalypts

The most important physical and mechanical properties of the main timber-producing eucalypts are given in Tables 3A to 3D. The nomenclature in these tables is in accordance with Australian Standard No. 0.2. The tables are arranged in three parts, corresponding with the availability of the respective timbers at current rates of production. Those being produced at rates exceeding ten million super feet annually are included in Availability Class 1 in the first part of Table 3A; those produced at rates from three to ten million super feet per annum are included in Availability Class 2 in the second part of Table 3B; those produced at one to three million super feet per annum are placed in Availability Class 3; and Availability Class 4 includes those produced at a rate under one million super feet per annum.

The densities are given for timbers in the green condition, and also in air-dry condition which for the purposes of this paper is at 12 per cent moisture content. The densities expressed in pounds per cubic foot are average figures for each timber, and it is shown that the heaviest, *E. siderophloia*, on the average weighs 80 pounds per cubic foot, green, and 71 pounds per cubic foot at 12 percent moisture content, while the lightest, *E. gigantea*, is on the average 65 pounds per cubic foot, green, and 39 pounds per cubic foot at 12 percent moisture content. The majority exceed 50 pounds per cubic foot at 12 percent moisture

content. Compared with other timbers, the eucalypts must be regarded as dense timbers.

The relative strengths are indicated by classifying the species into strength groups, the highest, Group A. including such timbers as *E. paniculata* and other ironbarks, and the lowest, Group D, which would apply to most softwoods of the world, but not to eucalypts, with the exception of *E. rostrata,* which is low in bending strength and stiffness. The strength classes are based on values for the main mechanical properties as listed in Table 2.

TABLE 2

STRENGTH GROUPS FOR PRINCIPAL EUCALYPT TIMBERS

Group	Modulus of rupture (lb. per sq. in.)		Modulus of elasticity (lb. per sq. in.)		Crushing strength parallel to grain (lb. per sq. in.)		Shear strength (lb. per sq. in.)	
	Green	12 percent moisture content	Green	12 percent moisture content	Green	12 percent moisture content	Green	12 percent moisture content
A	15,000	24,000	2,400,000	3,000,000	7,500	12,000	2,000	2,500
B	12,000	20,000	2,100,000	2,600,000	6,000	10,000	1,500	1,900
C	10,000	16,000	1,700,000	2,200,000	5,000	8,000	1,200	1,600
D	7,000	12,000	1,500,000	1,900,000	3,500	6,000	800	1,100

(*Note:* The above figures apply for defect-free timber only.)

In addition to the properties embraced by the strength grouping, others such as toughness and hardness are of interest. None of the eucalypts attains a toughness as high as that of American hickory; *E. astringens* is not far below, and *E. cornuta, E. maideni, E. diversicolor* and *E. maculata* are tough timbers. The property of hardness, determined by measuring the load in pounds required to embed a ball 0.44 in. diameter to half its depth, gives a general indication of the ability of the timber to withstand wear and abrasive forces, and gives also some guide to the facility with which timbers may be worked by either hand or machine tools. Among the hardest eucalypts are *E. hemiphloia, E. cornuta, E. paniculata* and *E. bosistoana,* and the species ranked as softest include *E. regnans, E. gigantea* and *E. rubida.*

Shrinkage is not particularly high in the eucalypts, except in species of the ash type in which *E. regnans, E. obliqua* and *E. gigantea* are the chief representatives. *E. redunca* var. *elata* with 2½ percent radial shrinkage and 3½ percent tangential from green to 12 percent moisture content, has the lowest shrinkage of the important eucalypts, while *E. corymbosa* with 3 percent radial and 4 percent tangential, *E. acmenioides* with 3 percent radial and 5½ percent tangential, *E. resinifera* and *E. siderophloia* each with 3½ percent radial and 5½ percent tangential deserve their reputation for stability.

The durability differs considerably between timbers. It is possible to distinguish four classes on the basis of the resistance of their truewood to decay and to termites. Timbers in Class 1—very durable—could be expected to have an average life of 20 to 25 years as poles under conditions favouring attack by the various agencies of deterioration found in Australia. Class 4—the non-durable class—includes timbers which can be expected to have a life of from three to five years when used under adverse conditions.

The sapwood of some eucalypts is susceptible to attack by the powder post

TABLE 3A

PROPERTIES AND USES OF EUCALYPTUS SPECIES IN AVAILABILITY CLASS 1

Standard Trade Reference Name	Standard Trade Common Name	Density (lb./cu. ft.)		Strength group	Durability class	Susceptibility to *Lyctus*	Shrinkage, green to 12% m.c.		Price class	Size class	Quality class	States where grown	Principal uses
		Green	12% m.c.				Rad.	Tang.					
E. diversicolor	Karri	73	57	B	3	I	5	10	B	A	A	W.A.	Sleepers, engineering construction, building framework and flooring, agricultural implements, vehicle construction, bentwork, stave pipes, cases, veneer.
E. gigantea	Alpine ash	65	39	C	4	R	5	8½	A	A	B	Vic. N.S.W. Tas.	Building framework, flooring and milled lines, interior fitments, furniture, oars, handles, sporting goods, vehicle construction, agricultural implements, cooperage, cases, veneer, paper.
E. grandis	Rose gum	59	41	C	4	R	3½	6½	B	B	B	N.S.W. Q.	Building framework and flooring, furniture, corestock, oars, cases.
E. maculata	Spotted gum	74	63	A & B	2 & 3	H	4	6	B	A	B	N.S.W. Q.	Engineering construction, shipbuilding, sleepers, vehicle construction, agricultural implements, bentwork, flooring, handles, veneer.
E. marginata	Jarrah	70	51	C	2	R	5½	8	B	B	B	W.A.	Poles, piles, posts, sleepers, engineering construction, shipbuilding, building framework and finish, vehicle construction, vats, furniture, cases, veneer.
E. microcorys	Tallowwood	76	62	A	1	M	4½	6½	C	A	A	N.S.W. Q.	Piles, poles, sleepers, engineering construction, building framework, flooring, weatherboards, sills, shipbuilding.
E. obliqua	Messmate stringybark	70	48	C	3	H	5½	11½	A	A	B	Vic. Tas. N.S.W. S.A.	Building framework, flooring, weatherboards, interior fitments, furniture, vehicles, general construction, poles, piles, sleepers, woodwool, paper.
E. pilularis	Blackbutt	70	56	B	2 & 3	R	4	7	B	A	B	N.S.W. Q.	Building framework, flooring and other milled lines, sleepers, engineering construction, shipbuilding, poles, vehicles.
E. regans	Mountain ash	63	44	C	4	I	7	14	A	A	B	Vic. Tas.	Flooring, weatherboards and other milled lines, joinery and interior fitments, building framework, furniture, handles, cooperage, vehicles, woodwool, paper.
E. rostrata	River red gum	75	56	D	2	M	4	8½	B	B	C	Vic. N.S.W. Q., S.A.	Engineering construction, sleepers, posts, poles, piles, felloes.

TABLE 3B

PROPERTIES AND USES OF EUCALYPTUS SPECIES IN AVAILABILITY CLASS 2

TABLE 3B

PROPERTIES AND USES OF EUCALYPTUS SPECIES IN AVAILABILITY CLASS 2

Standard Trade Reference Name	Standard Trade Common Name	Density (lb./cu. ft.)		Strength group	Durability class	Susceptibility to *Lyctus*	Shrinkage, green to 12% m. c.		Price class	Size class	Quality class	States where grown	Principal uses
		Green	12% m. c.				Rad.	Tang.					
E. acmenioides	White mahogany	80	59	B	1	R	3	5½	C	B	A	N. S. W. Q.	Engineering construction, sleepers, poles, piles, building framework, flooring.
E. capitellata	Brown stringybark	79	56	B	3	I	5	10½	A	B	B	N. S. W. V., S. A.	Building purposes.
E. crebra	Narrow-leaved red ironbark	80	67	A	1	R	4	8	C	A	A	N. S. W. Q.	Engineering construction, sleepers, poles, piles, flooring.
E. eugenioides	White stringybark	70	52	B	2 & 3	R	5½	10	B	B	B	N. S. W. V.	Engineering construction, sleepers, poles.
E. goniocalyx	Mountain grey gum	72	54	C	3	H	5	11	B	B	B	Vic. N. S. W.	Engineering construction, building purposes, vehicles.
E. paniculata	Grey ironbark	76	70	A	1	R	5	8½	C	A	A	N. S. W. Q.	Sleepers, engineering construction, vehicles, shipbuilding, piles, poles, posts.
E. propinqua	Grey gum	76	66	A	1	R	4	8½	C	A	B	N. S. W. Q.	Engineering construction, sleepers, poles, piles.
E. redunca	Wandoo	79	68	A	1	I	2½	3½	C	B	B	W. A.	Sleepers, vehicles, engineering construction, poles, piles, posts, flooring, tanning extract.
E. resinifera	Red mahogany	72	59	B	2 & 3	M	3½	5½	B	B	B	N. S. W. Q.	Building framework, flooring, weatherboards, joinery, engineering construction, sleepers, shipbuilding, poles, piles.
E. saligna	Sydney blue gum	70	52	B	3	M	5	9	B	B	B	N. S. W.	Building framework, flooring, weatherboards, vehicles, shipbuilding, sleepers, cases.
E. siderophloia	Broad-leaved red ironbark	80	71	A	1	R	3½	5½	C	A	A	N. S. W. Q.	Engineering construction, sleepers, poles, piles, vehicles, flooring.
E. sideroxylon	Red ironbark	77	66	A	1	H	4½	8	C	B	B	Vic. N. S. W.	Sleepers, engineering construction, poles, piles.
E. sieberiana	Silvertop ash	73	53	B	4	I	6½	9½	A	B	B	N. S. W. Vic. Tas.	Building framework, flooring, furniture, vehicles, posts, poles, handles, cases, paper.
E. viminalis	Manna gum	66	51	C	4	M	2½	9	A	B	B	Tas. Vic. N. S. W. S. A.	Building framework, flooring, joinery, vehicles, handles, cases.

TABLE 3C

PROPERTIES AND USES OF EUCALYPTUS SPECIES IN AVAILABILITY CLASS 3

Standard Trade Reference Name	Standard Trade Common Name	Density (lb./cu. ft.)		Strength group	Durability class	Susceptibility to *Lyctus*	Shrinkage, green to 12% m.c.		Price class	Size class	Quality class	States where grown	Principal uses
		Green	12% m.c.				Rad.	Tang.					
E. amygdalina	Black peppermint	..	..	C	3 & 4	H	...	...	C	B	B	Tas.	Building purposes, posts.
E. australiana	Narrow-leaved peppermint	68	47	C	3 & 4	H	7	13	C	B	C	N.S.W. Vic.	Building purposes, posts.
E. cloeziana	Gympie messmate	80	62	B	2	..	...	...	B	B	B	Q.	Sleepers, construction purposes.
E. corymbosa	Red bloodwood	70	55	B	1	M	3	4	B	B	C	N.S.W. Q.	Building framework, sleepers, mining timber, poles, piles.
E. dalrympleana	Mountain gum	73	42	C	4	H	4½	10½	B	B	B	N.S.W. Vic.	Building framework, flooring and other milled lines, furniture, handles, cases.
E. hemiphloia	Grey box	72	69	A	1	R	4	8	C	A	A	Vic. N.S.W. Q.	Engineering construction, sleepers, vehicles, mauls, piles, poles.
E. maideni	Maiden's gum	69	60	B	3	H	5½	10½	B	B	A	Vic. N.S.W.	Engineering construction.
E. muelleriana	Yellow stringybark	74	55	B	2	I	4	7	B	A	B	Vic. N.S.W.	Engineering construction, sleepers, building framework, flooring and other milled lines, shipbuilding, poles, piles.
E. tereticornis	Forest red gum	75	61	B	2	M	5	8	B	B	B	N.S.W. Vic. Q.	Engineering construction, sleepers, building framework, flooring, joinery, shipbuilding, poles, posts, mauls.
E. tesselaris	Carbeen	74	61	A	2	H	...	...	B	B	B	N.S.W. Q.	Engineering construction, sleepers, building.
E. torelliana	Cadaga	..	..	B	2 & 3	..	...	...	B	B	B	Q.	Building purposes.

TABLE 3D

PROPERTIES AND USES OF EUCALYPTUS SPECIES IN AVAILABILITY CLASS 4

TABLE 3D

PROPERTIES AND USES OF EUCALYPTUS SPECIES IN AVAILABILITY CLASS 4

Standard Trade Reference Name	Standard Trade Common Name	Density (lb./cu. ft.)		Strength group	Durability class	Susceptibility to *Lyctus*	Shrinkage, green to 12% m. c.		Price class	Size class	Quality class	States where grown	Principal uses
		Green	12% m. c.				Rad.	Tang.					
E. andrewsi	New England ash	..	..	..	2 & 3	S	...	...	...	...	...	N. S. W.	Building purposes, sleepers.
E. astringens	Brown mallet	69	61	B	2 & 3	I	4½	7	B	C	B	W. A.	Posts, handles, tanning material.
E. bosistoana	Coast grey box	79	69	A	1	R	4	8	C	A	A	N. S. W. Vic.	Poles, piles, sleepers, engineering construction.
E. botryoides	Southern mahogany	75	57	B	2 & 3	R	4½	9	B	B	B	N. S. W. Vic.	Sleepers, building and construction purposes.
E. calophylla	Marri	76	53	B	3	M	3½	6½	B	A	C	W. A.	Cases, handles, chemical wood.
E. cladocalyx	Sugar gum	75	68	B	2 & 3	H	6	10½	B	C	B	S. A.	Construction, posts.
E. consideniana	Yertchuk	73	59	B	2	R	6½	9	B	C	B	N. S. W. Vic.	Building purposes, sleepers.
E. fasciculosa	Pink gum	73	62	B	3	..	3½	6	B	B	C	S. A.	Building framework, mining.
E. fastigata	Brown barrel	69	48	B	.....	M	9	10	B	B	B	N. S. W. Vic.	Building framework, flooring, joinery, cases.
E. fraxinoides	White ash	66	42	B	3	S	4	6	B	B	B	N. S. W.	Building framework, flooring, internal fitments, cases.
E. globulus	Southern blue gum	69	56	B	3	M	5	11	B	B	A	N. S. W. Tas., Vic.	Piles, poles, engineering construction, sleepers, vehicles, shipbuilding, handles.
E. gomphocephala	Tuart	..	64	A	1	M	...	...	A	A	A	W. A.	Vehicles, engineering construction, handles.
E. haemastoma	Scribbly gum	..	..	C	2 & 3	S	...	...	B	A	C	N. S. W. Q.	Building purposes, cases.
E. leucoxylon	Yellow gum	75	62	B	1	H	3	6	B	B	B	Vic. S. A.	Poles, sleepers, engineering construction.
E. longifolia	Woollybutt	..	65	B	2	H	...	...	B	B	B	N. S. W.	Building purposes, sleepers, poles.
E. melliodora	Yellow box	78	66	B	1 & 2	R	3	6	B	B	B	N. S. W. Q., Vic.	Sleepers, poles, posts, construction purposes.
E. nitens	Shining gum	64	41	C	4	H	5	9	B	B	A	N. S. W. Vic.	Joinery, flooring and other other milled products, handles, oars, building framework.
E. patens	W. A. blackbutt	70	54	B	3	M	...	...	B	B	B	W. A.	Joinery, vehicles, flooring, building framework, sleepers, cases.
E. rubida	Candlebark	..	46	C	3 & 4	M	...	...	B	B	B	N. S. W. Vic., Tas. S. A.	Building purposes.

borer (*Lyctus* sp.), and others are completely immune. Relative susceptibility is described in the terms—Highly susceptible H, Medium susceptibility M, Rarely attacked R, and Immune I. In Tables 3A to 3D the appropriate marking is placed against each species.

As a general guide to potential consumers, indication of relative price, sizes available, average quality and availability are given in the table.

Finally, the States in which the respective species occur, and the principal uses to which they are put in Australia, are indicated.

The eucalypts are utilized in Australia for many purposes summarised in Table 3. In attaining their place in industry, eucalypts have had to overcome many of the prejudices of people schooled in the traditional uses of softwoods as all-purpose timbers; to demonstrate characteristics offsetting the advantages, such as the lighter weight and easier working of popular softwood species; and to meet at various periods difficult price competition.

Their main use is for building purposes. In this sphere their durability, strength and hard wearing characteristics are used to advantage. Species of high durability and strength are chosen for building foundation members and bearers; others are used for building framework; and the species of light weight, high grade or decorative value are the most popular for flooring and internal finish. Many are used for external sheathing as weatherboards.

Engineering construction is most commonly carried out with the strongest or most durable species. A use of great importance is that of railway sleepers, and in this application the high strength and

TABLE 4

USE OF TIMBER IN AUSTRALIA

	All timbers		Eucalypts	
	Millions of super feet			
Sawn and hewn timber				
Construction				
Dwellings	350		270	
Buildings for other purposes	128		80	
Engineering construction	180		150	
Sub-total, construction		658		500
Manufacturing				
Furniture	80		38	
Vehicles—Ships	12		8	
Agricultural implements	5		3	
Turnery	20		8	
Cooperage	6		1	
Coffins	4		2	
Miscellaneous	38		22	
Sub-total, manufacturing		165		82
Cases and crates, sub-total		227		78
Total, sawn timber		1,050		650
Total equivalent in log measure		2,220		1,630
Round timber		113		105
Veneer logs		44		11
Pulpwood		135		128
Firewood		1,456		1,350
Chemical charcoal wood		177		160
Grand total		4,145		3,385

bearing capacity of the eucalypts allow railway rails to be dogged directly on to the wooden sleepers without wearing plates or chairs.

In the manufacturing field certain eucalypt species are the mainstay of industries manufacturing agricultural implements, wheelwrights' products, vehicle bodies, cooperage and certain classes of furniture.

Some manufacturers of cases and crates use eucalypt species exclusively.

The eucalypts contribute 650 million super feet in a total supply of Australian and imported timber totalling 1050 million super feet per annum. During periods of high industrial activity the main divisions of consumption are as shown in Table 4. An estimate of the approximate quantities supplied by eucalypts is given in Column 3 of the table.

Acknowledgment

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Selected Bibliography

Von Mueller, Baron F. (1879/94). Eucalyptographia: descriptive atlas of the eucalypts of Australia and the adjoining islands. Decades I–X.

Maiden, J. H. (1903/31). Critical revision of the genus Eucalyptus, vols. 1–8. Govt. Printer, Sydney.

Baker, R. T. (1919). Hardwoods of Australia and their economics. (Tech. Mus., Sydney, Tech. educ. ser. no. 23). Govt. Printer, Sydney.

Baker, R. T., and Smith, H. G. (1920). Research on the eucalypts, especially in regard to their essential oils 2nd ed. (Tech. Mus., Sydney, Tech. educ. ser. no. 24). Govt. Printer, Sydney.

Blakely, W. F. (1934). Key to the eucalypts, and companion to J. H. Maiden's Critical revision of the genus Eucalyptus. Author, Sydney.

Carter, C. E. (1945). Distribution of the more important timber trees of the genus Eucalyptus. pp. 8 + 42 maps. (Commonwealth For. Bur., Atlas no. 1). Govt. Printer, Canberra.

Penfold, A. R. (1944). Commercial eucalyptus oils. 4th ed. (Tech. Mus., Sydney, Bull. 2). Govt. Printer, Sydney.

Victoria, Dept. Agr. (1935). Honey flora of Victoria. 3rd ed. Govt. Printer, Melbourne.

Coghill, D. C. (1927). Survey of the tanning materials of Australia. (Coun. Sci. Ind. Res. (Aust.) Bull. 32). Govt. Printer, Melbourne.

Langlands, I., and Thomas, A. J. (1941). Handbook of structural timber design. 2nd ed. (Coun. Sci. Ind. Res. (Aust.), Div. Forest Products, Tech. paper 32). Govt. Printer, Melbourne. *Same.* Supplement no. 1,—Large timber structures: notes on design, specification and inspection, by I. Langlands, 1942, with Addendum.

Standards Assoc. Aust., Sydney. Nomenclature of Australian timbers. Tech. Std. 0.2: 1940. (Coun. Sci. Ind. Res. (Aust.), Div. Forest Products, Trade circ. 47). Australian standard grading rules (Emergency series) for sawn and hewn structural timbers. Standard (E) 0.54–1942.

Bulrushes and Their Multiple Uses

None of the species of the genus Scirpus—including clubrushes, bulrushes, tules and woolgrasses—is of great economic importance, but in the aggregate its members fill many needs in the fields of conservation, wildlife and food supply, as well as isolated needs in the fields of basketry, transportation and horticulture.

ALAN A. BEETLE [1]

Introduction

The first use of historical significance that comes to mind in connection with bulrushes is the biblical story of the hiding of the infant Moses. It is probably best at the start, then, to disclaim for *Scirpus* this time-honored tradition, for it seems more properly to belong to a member of the genus *Cyperus*, the Egyptian papyrus.

There are some 150 members of the genus *Scirpus*. The North American species have been described (4), and the more common illustrated (6). During the long years of human development many uses for them have been found. Some of these are now only of ethnological interest, some are declining in importance, others are newly recognized and may be expected to increase in importance as the new fields of conservation develop. On a negative but nevertheless economic side is the presence of species of *Scirpus* as weeds in many areas where their control has proved difficult and costly.

Common Names

Considerable confusion apparently exists regarding common names for *Scirpus*. The following notes may be of help in clarifying the situation and in explaining the choice of common names used in this paper. The term "bulrushes" (occasionally spelled "bull rushes") has been used in a loose sense to cover all members of the genus. The clubrushes (as contrasted with the spikerushes which are all species of *Eleocharis* and with the true rushes of the Juncaceae) are the members of the sections of *Scirpus* which tend to be leafless, *i.e.*, Sections Baeothryon (A. Dietr.) Reichenb., Eleogiton (Link) Reichenb., Isolepis (R.Br.) Griseb., Actaeogeton Reichenb. and Schoenoplectus Reichenb. The only exception is that of the tules (occasionally spelled "thules"), all of which comprise the Section Pterolepis (Schrad.) Endl.

The true bulrushes comprise sections of *Scirpus* which tend to be leafy, *i.e.* Sections Oxycaryum (Nees) Beetle, Bolboschoenus (Asch.) Beetle and Taphrogeton Reichenb. Here the only exception is that of the woolgrasses (as contrasted with the cottongrasses which are species of *Eriophorum*), all of which comprise the Section Trichophorum (Pers.) Darl.

Some vernacular names for *Scirpus* have been compiled (13, p. 117).

Weaving Material

Mats, Baskets, etc. Rusby (19) goes so far as to say that the bulrushes represent "one of the most important uncultivated textile materials in the world". This high praise applies mainly to the

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widespread New World members of the Section Pterolepis, including particularly the giant tule (*S. validus* Vahl), the alkali tule (*S. acutus* Muhl.), the California tule (*S. californicus* (Mey.) Steud.) and *S. tatora* Kunth. Wherever available they have been used by Indian tribes for basketry, roof thatching, mat making and the like. Muller (15), in describing the industrial fiber plants of the Philippines, reports that " various species of *Scirpus*, such as *S. erectus*, *S. grossus*, *S. lacustris*, and *S. mucronatus*[2] find occasional uses for different purposes ".

Alkali tule was very important in the Indian cultures of western North America. M. L. Zigmond reports (see Zigmond 7, from Kern County, Piute Mountains, California; June 18, 1937, sheet in the Herbarium of the Field Museum, Chicago) it used for mats of various types and as roofing. In the latter capacity the tules are woven into overlapping shingles as an external covering over a brush filler.

Boats. *S. tatora*, although restricted to high elevations of Peru and Bolivia, has considerable economic importance and is called " totora " by the natives of those regions. Growing as it does in places where trees were always absent until the Australian *Eucalyptus* was recently introduced, it was put to as many wood-substitute uses as possible. On Lake Titicaca, the great interandine water highway, whole boats—hull, spars and sails—are constructed from the culms which are cleverly lashed together. The Indians float these " balsas " several miles from shore until they are waterlogged and then haul them into the sun to dry out. For further information on these interesting boats, see citations 3, 9, 16, 21, the first and third of which are profuse in illustrations of the sedge boats.

[2] *S. erectus* Poir, *S. grossus* L. f., *S. lacustris* L., *S. mucronatus* L.

Conservation

Wildlife Protection. Tall species of the genus, occurring as they do along slow streams, on lake margins and around isolated ponds, often serve not only as shelter for wildlife but also as food.

In the years 1935–1941 the U. S. Department of Interior, Fish and Wildlife Service, engaged in the restoration of the native vegetation and the introduction of other species throughout the nation's refuge system. During this period a considerable quantity of marsh, or prairie, bulrush (*S. paludosus* Nels.) was planted at the upper end of the Colorado River Reservoir, or, properly speaking, Mead Lake.

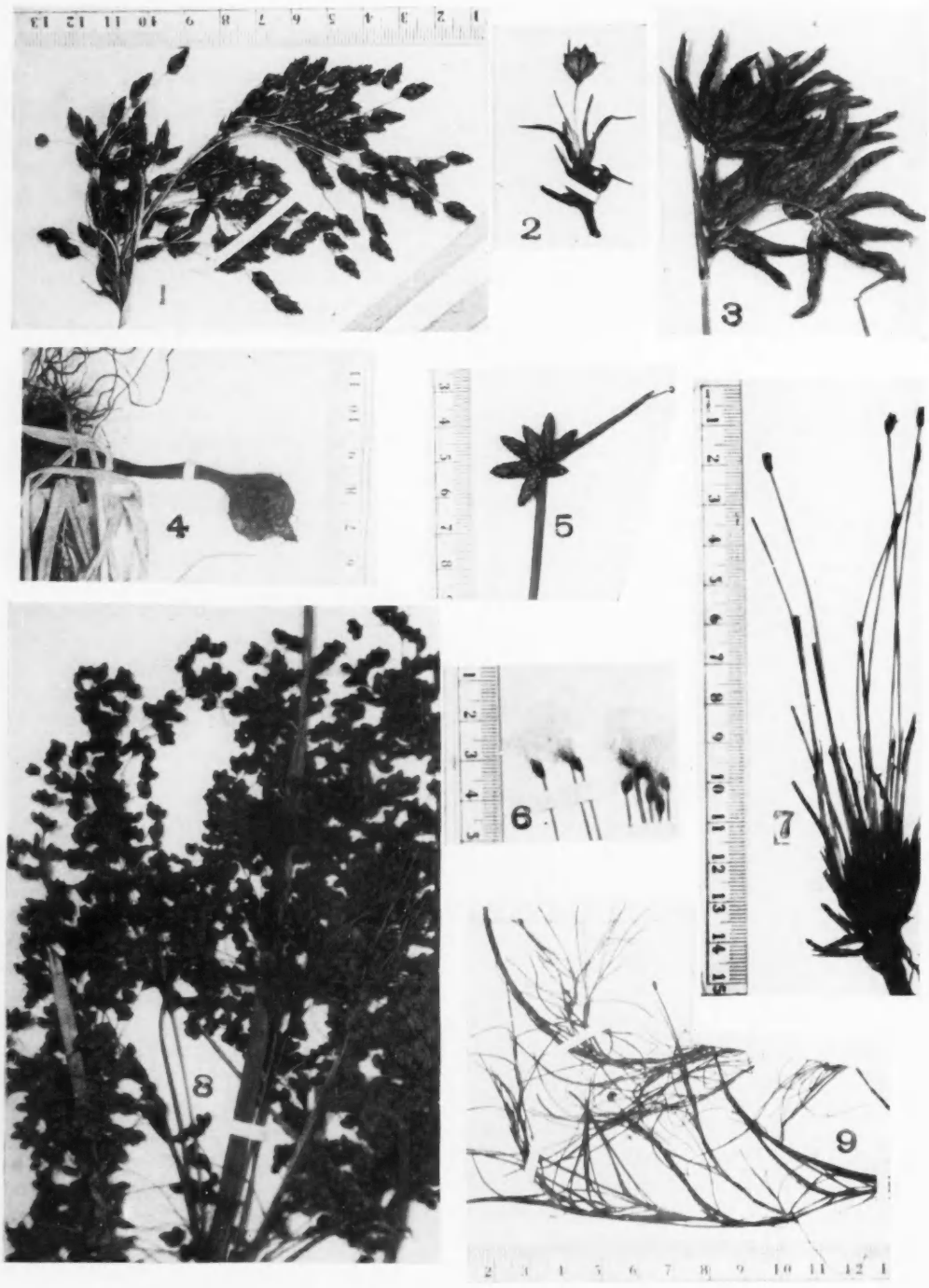
Williams and Sooter (20) reported that certain types of vegetation are more valuable than others in providing suitable nesting sites for the Canada goose. In northern Utah and southeastern Oregon the best of the plants was alkali, or hardstem, tule (*S. acutus*). Also on the list but not so important, because a much rarer plant if for no other reason, was Olney's club-rush (*S. chilensis* Nees).

Williams and Sooter (20) also report that " In general, muskrat lodges add to the attractiveness of all emergent cover types. Their influence, of course, depends upon number, location, and character of other available sites. At Malheur, 33 percent of all nests[3] among hardstem bulrushes were on muskrat lodges. At Bear River muskrat activity was largely responsible for the nesting utilization of alkali bulrush (*S. paludosus*), inherently a poor cover ".

Kubichek (11) reports that in North Dakota, grain combines have been used to gather a yield of *S. paludosus* seed " 7 to 12 bushels per acre, and weighing 40 pounds per bushel was realized at a cost of $0.0063 a pound, or $0.25 a bushel, for harvesting ".

S. chilensis, *S. fluviatilis* (Torr.) Gray and all the tules have been reported

[3] Canada goose nests.



A survey of the great morphological variation found in the genus *Scirpus*. (*Photos courtesy of F. A. Knittle.*) FIG. 1. *Scirpus validus*, one of the tules. FIG. 2. *S. acaulis* Phil., a tiny South American species. FIG. 3. *S. tuberosus* Desf., one of the European bulrushes now introduced in North America. FIG. 4. The swollen tuber of *S. paludosus*, used by Indian tribes as food. FIG. 5. *S. mucronatus* L., a weed in California rice fields. FIG. 6. *S. hudsonianus* (Michx.) Fern., although conspicuously cottony, is neither a true cottongrass nor a true woolgrass. FIG. 7. *S. cespitosus* var. *callosus*, reindeer feed of the north. FIG. 8. *S. cyperinus* var. *eriophorum*, one of the woolgrasses. FIG. 9. *S. fluitans* L., a true aquatic.

many times as excellent muskrat cover (*cf.* 23).

Streambank Protection. The heavy root system of many *Scirpus* species not only acts as a good soil binder but contributes largely to the building of rich delta lands (e.g. *S. californicus, S. acutus*) and even to conquering tidal estuaries (e.g. *S. rubiginosus* Beetle).

S. cyperinus (L.) Kunth. var. *eriophorum* (Michx.) Kuntze is a large, leafy and, when flowering, beautiful woolgrass which has an excellent combination of qualifications necessary for streambank protection. Performing just this task the plant is pictured by Kearns (10*a*, p. 147).

Rhizome fragments of the perennial species of *Scirpus* transplant readily, often standing even a considerable amount of drying. This is the most practical, surest and quickest method of establishment. Little work has been done on establishment through seeding. Experimental work performed by the author has led to the conclusion that all *Scirpus*, and probably all sedge, seeds are emersal, *i.e.*, they float for several days or, in some cases, for several months. The ability to float is at least a partial test of ability to germinate. *Scirpus* seeds never germinate while floating on the water, those lying on soil and covered with water germinate most rapidly, and those covered with soil and water much more slowly. For more detailed studies of the seed germination of species of *Scirpus*, see Isely (10).

Food

Seeds. Of the 14 species of plant that Metcalf (14) considers most important as food for wild duck in North Dakota, five are species of *Scirpus*. Other writers (12, 13) also give considerable information regarding the utility of *Scirpus* species as duck food. " Parts of plants of the genus *Scirpus* have been found in the stomachs of thirty-one species of American wild ducks, six of geese, and one swan. It is usually the roots that are eaten, and the rootstocks and herbage chiefly sought by the geese form only a slight proportion of the food of ducks. The most frequent consumers of bulrush seeds appear to be the mallard, pintail, green-winged and blue-winged teals, and the lesser scaup " (13).

Ridley (18) accounts for many distributions in the genus on the basis of dispersal by ducks, either through the sticking of seeds to mud on the birds' feet or by passing through the stomach unharmed. A key for the identification of *Scirpus* seeds found in bird stomachs has been compiled for North American species (2).

The large and abundant achenes of the following species also constitute important bird food, particularly for ducks:

S. cubensis Poepp. & Kunth. Recognized as food for the American Mallard (duck) and also for the pintail (18).

S. americanus Pers. Seeds of the American clubrush were found in the stomachs of 20 kinds of duck and two of geese. In a single stomach of a canvasback there were 5,228 seeds (13).

Roots and Shoots. *S. acutus.* The succulent roots were used as thirst quenchers by Indian tribes of western North America.

S. tatora. Indian tribes in the high Andes use the tender young shoots of their " totara ".

S. paludosus. Swollen tubers on the roots are used as food by Indian tribes of western North America.

S. grossus f. *kysoor* (Roxb.) Beetle. In India the roots are called " bid " and are used as a famine food in Ahmedabad (17). Bid contains about 70 percent of digestible carbohydrate, 8 to 10 percent of protein. When used for human food the clods dug from the soil containing the rhizomes are left unbroken until thoroughly dried.

Herbage. In the West where the wet

meadows are usually characterized by rushes and sedges, the species of *Scirpus* have often been a component of meadow pasture and native hay, on both fresh soils and those which are alkaline. In recent years the practice of flood irrigation has often increased considerably the area in which these plants may be found. Because of this, chemical analyses on three species were run by the University of Wyoming Agricultural Experiment Station (22). In Studies No. 3 red-tinged bulrush (the plant analyzed was actually *S. rubrotinctus* Fern. although labeled *S. microcarpus* Presl—see page 81) was analyzed and listed as "one of the best. It prefers stream and pond banks, but occurs to some extent in the wetter meadows and makes a very acceptable ingredient of the hay". In Studies No. 4 great bulrush (the plant analyzed was actually *S. validus* although labeled *S. lacustris*—see page 124) was analyzed and listed as "of little importance as forage, except, perhaps, in very marshy land. Cattle occasionally browse it down". In Studies No. 4 clubrush (the plant was actually *S. americanus* var. *polyphylus* (Boeckl.) Beetle although labeled *S. americanus*—see pages 126–127) [4] was analyzed.

S. cespitosus L. var. *callosus* Bigel is the niggerhead, deerhair, or scaly clubrush, abundant in arctic regions where it is an important reindeer feed.

Horticulture

Bailey (1) lists only two Old World species, *S. cernuus* Vahl and *S. lacustris* var. *tabernaemontani* (Gmel.) Doell. f. f. *zebrinus* (Nichols) [5], as cultivated for horticulture. The former is listed as "frequent in pots and as edging in greenhouses", the latter as "marked on the culm by alternate broad bands of green and white". Neither is common in gardens in the United States. The unusual variegation exhibited by the tule may be seen on a herbarium specimen in the California Academy of Sciences.

Chemical Analyses of Three Bulrushes
Made by the Wyoming Agricultural Experiment Station

	Water	Ash	Ether extract	Crude fiber	Crude protein	Nitrogen-free extract
S. rubrotinctus[1]						
Green	68.34	4.41	0.82	8.18	4.48	13.77
Air dry	5.73	13.13	2.45	24.35	13.33	41.01
Water free	....	13.93	2.60	25.83	14.14	43.50
S. validus[2]						
Air dry	5.00	10.74	1.08	30.93	9.55	42.70
Water free	....	11.30	1.14	32.56	10.05	44.95
S. americanus[3] var. *polyphyllus*						
Air dry	5.59	12.37	1.22	28.29	10.59	41.94
Water free	....	13.10	1.29	29.97	11.22	44.42

[1] Gathered August 10, 1907, on marshy land near Jelm, Wyo. Past bloom.
[2] Gathered July 19, 1908, in a slough at Wendover, Wyo. Altitude about 4,000 feet. Partly in bloom. Somewhat colored in curing.
[3] Gathered July 27, 1910, on river bank at wagon bridge northwest of Laramie, Wyo. In bloom.

[4] These were not misidentifications but usage of the accepted names of the time which were subsequently altered as more became known of the flora of the region and the taxonomy of the genus (4).

[5] This plant is also referred to in horticultural literature as *Juncus zebrinus* Hort. and *S. tabernaemontani* Gmel. var. *zebrinus* Nichols.

Perhaps as deserving of cultivation as the above are two truly American species: the North American woolgrass, *S. cyperinus* var. *eriophorum*, whose ample and bright terra cotta inflorescence would add color to any pool margin; and the giant of all leafy bulrushes, the South American *S. giganteus* Kunth, of which the striking brick-red spikelets would blend well amid the dark greens of cattail, flag and willows in pool and stream plantings.

Miscellaneous Notes and Uses

Gleason (18) reports the culms of *S. validus* (presumably meaning *S. acutus*, since he was working with those plants commonly found in the Douglas Lake region) good material for demonstrating the differentiating stages of procambial tissue.

In the treeless wastes of the high Andes the dry culms of *S. tatora* are used as fuel.

The cucumber beetle (*Diabrotica 11-punctata*), one of the pests whose control is of commercial importance, feeds on the pollen of *S. paludosus*.

Eleocharis dulcis (Burm. f.) Trin., sometimes referred to as *Scirpus tuberosus* Roxb., is the water chestnut of southern China and the East Indies but is not properly included in the genus *Scirpus*. Its tuber is sweet and juicy with a chestnut flavor and is universally used as food. Also a kind of arrowroot is made from it.

Aecia of *Puccinia angustata* Peck have been produced on *Mentha canadensis* L. by using telia from *Scirpus atrovirens* Willd. (7).

Weedy Tules and Bulrushes

S. mucronatus has been reported to be "a new pest of major importance, a weed which at this writing occurs over an estimated 10,000 acres in the rice-growing section of northern California, and in some fields constitutes up to 75 percent of the stand" (5). *S. tuberosus* Desf., like *S. mucronatus*, is also a weed in California rice fields, but seems not to be common as yet or to have caused damage to any stands.

All species of Section Pterolepis are vigorously stoloniferous and where common are so well adapted to the habitat created by the flooding of irrigation ditches that they quickly colonize and clog them, slowing stream flow and necessitating costly clearing operations. Normal stream flow has been reduced in severe cases to one-third if all other factors were held constant.

The same problems which present themselves in rice fields and irrigation ditches are present to a lesser degree on farms where small fish-rearing ponds have been established.

Bibliography

1. Bailey, L. H. Manual of cultivated plants. pp. 123–124. 1924.
2. Beetle, A. A. A key to the North American species of the genus *Scirpus* based on achene characters. Am. Mid. Nat. **29**: 533–538. 1943.
3. ———. Sedge boats in the Andes. Jour. N. Y. Bot. Gard. **46**: 1–4. 1945.
4. ———. *Scirpus*. North Am. Flora **18**: 481–504. 1947.
5. Bellue, M. K. Rough-seed bulrushes, *Scirpus mucronatus* L. A menace to rice production. Bull. State Dept. Agr. Calif. 3rd Qtr. pp. 91–96. 1947.
6. Fassett, N. C. A manual of aquatic plants. 382 pp. 1940.
7. Fraser, W. P. Cultures of heteroecious rusts in 1918. Mycologia **11**: 129–133. 1919.
8. Gleason, H. A. *Scirpus validus* for demonstrating procambium. Rep. Michigan Acad. Sci. **20**: 153. 1941.
9. Hitchcock, A. S. A botanical trip to Ecuador, Peru, and Bolivia. Smithsonian Report for 1924, pp. 335–351—pl. 15, fig. 1. 1925.
10. Isely, D. A study of conditions that affect the germination of *Scirpus* seeds. Cornell Univ. Agr. Exp. Sta., Mem. 257: 1–28. 1944.

10*a*. Kearns, M. C. Farm game program in Maryland. Soil Cons. **14** (7): 147. 1949.

11. Kubicheck, W. F. Collecting and storing seeds of waterfowl food plants for propagation. Trans. Fifth North Am. Wildlife Conf. p. 365. 1941.
12. Martin, A. C., and Uhler, F. M. Food of game ducks in the United States and Canada. U. S. Dept. Agr., Tech. Bull. 634. 1939.
13. McAtee, W. L. Wildfowl food plants. 141 pp. 1939.
14. Metcalf, F. P. Wild duck foods of North Dakota lakes. U. S. Dept. Agr., Tech. Bull. 221. 1931.
15. Muller, T. The industrial fiber plants of the Philippines. Jour. N. Y. Bot. Gard. 16: 75. 1915.
16. Parodi, L. R. Las balsas usadas por los Aymarás en el Lago Titicaca. Physis 11: 145–149. 1932.
17. Pathak, G. P. Some famine foods in Ahmedabad. Agr. Jour. India 15: 40–45. 1920.
18. Ridley, H. N. The dispersal of plants throughout the world. 744 pp. 1930.
19. Rusby, H. H. Report of the botanical work on the Pacific Coast. Jour. N. Y. Bot. Gard. 10: 229. 1909.
20. Williams, C. S., and Sooter, C. A. Canada goose habitats in Utah and Oregon. Trans. Fifth North Am. Wildlife Conf. pp. 384–385. 1941.
21. Williams, R. S. A collecting trip to Bolivia. Jour. N. Y. Bot. Gard. 4: 61. 1903.
22. Wyoming Agr. Exp. Sta. Wyoming forage plants and their chemical composition—Studies 3, 4 and 5. Wyo. Agr. Exp. Sta., Bull. 76: 81; Bull. 87: 124; 28th Ann. Rpt.: 126–127. 1908–1918.
23. Yeager, L. E. Capacity of Illinois land types to produce furs. Trans. Tenth North Am. Wildlife Conf.: 79–86. 1945.

Utilization Abstract

New Naval Stores Product. Maleopimaric acid, a new naval stores product developed by the U. S. Department of Agriculture, has possibilities for use in the preparation of plasticizers, resins and emulsifying agents. The development has reached a stage where commercial testing is feasible and where samples for tests are available on request to prospective users.

Recent work on maleo-pimaric acid has been financed by funds provided under the Research and Marketing Act of 1946, and has been carried out at the Naval Stores Station in Olustee, Florida, pilot plant of the Naval Stores Research Division. The pilot-plant investigations have been based on earlier laboratory-scale research and on a process for refining oleoresin, covered by U. S. Patent No. 2,359,980 granted to a member of the Naval Stores Research Division and assigned to the Secretary of Agriculture for licensing to responsible firms and individuals on a royalty-free, non-exclusive basis.

Maleo-pimaric acid is the adduct—addition product—of maleic anhydride with the levopimaric acid of pine gum. It is a white, crystalline, tribasic product with an acid number in acetone solution of 420 and a molecular weight of 400. The pure product (produced in small quantities in the laboratory) melts at 229° to 230° C., while maleo-pimaric acid produced in the pilot plant has a slightly lower melting point (222° to 225° C.). Maleo-pimaric acid is soluble in acetone, ether, alcohol and aromatic solvents, and is practically insoluble in alaphatic hydrocarbons.

The properties of maleo-pimaric acid are such that it should find successful application in alkyde-type resins and in sizing agents. The low volatility of its alkyl esters and their compatibility with many resins indicates promise as a plasticizing agent. The soap of ethyl maleo-pimaric acid has been evaluated on a pilot-plant scale as an emulsifier in the preparation of a synthetic rubber. The rubber produced compares favorably in quality with standard GR-S 10 (Ind. & Eng. Chem. **41**: 1296. 1949).

Concerns or individuals interested in testing this product for possible commercial application may obtain samples by writing to the Naval Stores Research Division, Southern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, 2100 Robert E. Lee Boulevard, New Orleans 19, Louisiana. (E. L. Patton).

Domestic Production of the Essential Oils of Peppermint and Spearmint

The average annual domestic production of mint oils for the past ten years stands at 1,410,000 pounds. This represents a farm value ranging from two to nine million dollars. It is in the production of mint oils that the volatile-oil industry reaches its peak in specialization and mechanization.

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Introduction

Several volatile oils are purchased in large quantities for use in the United States but relatively few of them are produced here commercially. Domestic production has been limited, due to certain causes, not the least of which is the high cost of labor; the oils that are being produced in the United States, therefore, are those that can be handled with a minimum labor expenditure.

Peppermint oil is one of the most widely used of the volatile oils. It has certain definite pharmaceutical properties and is used extensively as a flavoring. It has been estimated that approximately five percent is employed in pharmaceutical preparations, 15 percent in miscellaneous flavorings, 15 percent in dentifrices, 15 percent in confections and about 50 percent in chewing gum. Spearmint oil is used primarily for flavoring chewing gum and dentifrices.

The production of peppermint and spearmint oils in the United States is second only to that of turpentine in the volatile-oil industry. The oil is obtained entirely from cultivated fields, and it is in mint production that specialization in culture and mechanization for the production of a volatile oil reaches its greatest stage of advancement.

The United States dominates the world's production of mint oils so that the price is influenced by the quantity and quality of the domestic crop.

History

Peppermint oil and herb have been used for centuries for medicinal purposes. Crude techniques of distillation were practiced by the ancients, but the first written account on the subject was published in the year 410 A.D. by Synesius of Alexandria, the Bishop of Ptolemais. Tamba Yasuyori published a Japanese medical book in 984 that described the use of peppermint oil in an eye wash (5).

The peppermint oil of today was first mentioned in 1696 by an Englishman, John Ray, and it is thought that commercial distillation of the oil in England began shortly thereafter (1).

Additional uses for peppermint were found and there was a steady increase in production. Lyson (3) reported in 1796 that there were 100 acres of peppermint planted at Mitcham or in County Surrey, England. The world's production of oil at that time is thought to have been between 2,000 and 3,000 pounds.

Peppermint planting stock for the United States was imported from England about 1812, and the first plantings were made in the vicinity of Ashfield,

Massachusetts. About 1816 some growers from the Ashfield area moved to New York and established a mint industry there (6). Wayne County, New York, soon became the leading oil-producing center in the country, but serious competition came with the establishment of plantings in Ohio and, about 1835, in St. Joseph County, Michigan. The muck lands of southern Michigan and northern Indiana proved so well adapted to mint culture that the center of the industry soon became located there. The principal producing areas in Michigan are in the vicinities of St. Johns, Kalamazoo, Decatur and Imlay City, and the main areas in Indiana are near South Bend, North Judson, Rensselaer, Bremen, Nappanee and Columbia City.

Another mint-producing area entered the picture about 1919 with the establishment of plantings in Oregon and Washington. The industry there has expanded rapidly, and today that section can be divided into four more-or-less distinct areas. These are the Kennewick district between Kennewick and Yakima, Washington, in the Yakima Valley; the lower Columbia River district extending along the river from Puget Island, Washington, through Columbia County, Oregon (including an area near Longview, Washington); the Eugene district located along the McKenzie River just outside Eugene, Oregon; and the Salem district in the Willamette Valley near Jefferson and Albany, Oregon.

The history of spearmint culture is less well known, but undoubtedly this crop has been grown for many years in conjunction with peppermint. The main spearmint-producing areas are in Michigan and Indiana, although it has been introduced on the West coast in recent years.

Statistics

Accurate statistics on the production of mint oil are not available for the early years in the United States. Michigan succeeded Wayne County as the leading producer of peppermint oil, but acreages there have been declining steadily in recent years. The 1935–1944 average acreage was 18,220; 15,000 acres were grown in 1945; 14,000 acres in 1946; 13,500 acres in 1947; and 10,000 acres in 1948. Much of this drop has taken place in Clinton County, north of Lansing, where at one time 19,000 acres of peppermint were grown. This acreage had decreased to 13,000 in 1939, and by 1946 only 2,300 acres were planted to peppermint. The rapid decline of the peppermint acreage in Clinton County is directly traceable to the infestation of the soil with the organism causing verticillium wilt. With the decline in production in Michigan, Indiana took over the leadership and held that position until recently when the Oregon production has exceeded, slightly, that of Indiana. The latest statistics on acreage and production are shown in Table 1.

Taxonomy

The origin of commercially-grown mints is obscure, but most botanists agree that they are probably the result of natural hybridizations that occurred many years ago. There is considerable circumstantial evidence to support this theory, although no one has yet produced either peppermint or spearmint by controlled crosses involving the species reputed to be the parents.

Peppermint (*Mentha piperita* L.), according to Millspaugh (8), is a native of the Mediterranean countries, and, since it rarely sets seed, some workers (1, 2, 7, 8) have concluded that it is a hybrid. They postulate that the parents were *M. spicata* L. and *M. aquatica* L. Schürhoff (9) believes that *M. spicata* itself is a hybrid from a cross between *M. sylvestris* L. and *M. rotundifolia* L., however, thereby suggesting that *M. piperita* is in reality a threeway cross involving *M. aquatica*, *M. sylvestris* and *M. rotundifolia*.

TABLE 1

PEPPERMINT AND SPEARMINT PRODUCTION IN THE UNITED STATES AS REPORTED SEPTEMBER 9, 1949, BY THE BUREAU OF AGRICULTURAL ECONOMICS OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

Crop and state	Acreage			Yield per acre			Production		
	10-year average 1938–47 [1]	1948	Indicated 1949	10-year average 1938–47 [1]	1948	Ind. 1949	10-year average 1938–47 [1]	1948	Indicated 1949
	Acres	*Acres*	*Acres*	*Lbs. of oil*			*1,000 lbs. of oil*		
Peppermint and Spearmint:									
Indiana	19,290	27,300	26,400	27.9	34.5	28.2	549	942	745
Michigan	18,210	16,700	15,500	25.6	29.2	24.5	474	488	380
Ohio	150	.....	.....	32.2	...	...	4	...	...
California	710	.....	.....	37.2	...	...	26	...	...
Oregon	5,210	12,600	14,500	42.5	45.0	42.0	230	567	609
Washington	2,790	4,800	4,700	44.4	55.0	45.0	126	264	212
Total 6 States	46,360	61,400	61,100	30.2	36.8	31.8	1,410	2,261	1,946
Peppermint:									
Indiana	14,180	14,300	16,000	26.8	35.0	29.0	384	500	464
Michigan	15,770	10,000	9,500	24.4	22.0	21.0	395	220	200
Ohio	150	.....	.....	32.2	...	...	4	...	...
California	600	.....	.....	37.5	...	...	21	...	...
Oregon	5,210	12,600	14,500	42.5	45.0	42.0	230	567	609
Washington	2,790	4,800	4,700	44.4	55.0	45.0	126	264	212
Total 6 States	38,700	41,700	44,700	29.9	37.2	33.2	1,160	1,551	1,485
Spearmint:									
Indiana	5,110	13,000	10,400	30.8	34.0	27.0	166	442	281
Michigan	2,440	6,700	6,000	32.4	40.0	30.0	80	268	180
California	110	.....	.....	43.4	...	...	5	...	...
Total 3 States	7,660	19,700	16,400	31.8	36.0	28.1	250	710	461

[1] For group totals and for all States, averages of the annual total, *not* the sum of the State or group averages.

Three strains of peppermint called "black", "American", and "white" are reported to occur in commercial areas. The black mint, sometimes called "Black Mitcham" or "English mint", is by far the most extensively grown of the three, although some American mint can be found in certain areas. It is doubtful that any of the white mint, sometimes called "white Mitcham", is now grown commercially.

Black peppermint has dark-green to deep-purple branching stems bearing deep-green, opposite, broadly-lanced, slightly toothed leaves. The stems are described as being "square" which is typical of the mints in general. The flowers are lavender to purple in color and occur in terminal spikes on the main axis and branches. Black peppermint grows to a height of one and one-half to five feet, depending on cultural and weather conditions.

American mint is similar to black mint except that it has greener stems and lighter green leaves. It was probably the first variety grown in the United States, but because it yields poorly, an effort is being made by growers to eradicate it.

White mint is smaller than black mint and, although it is reputed to produce a higher grade oil, it is not grown because it is not hardy and yields less oil.

Spearmint (*M. spicata* L.) apparently was introduced from Europe also and several varieties can now be found growing wild over the eastern United States. The term "spearmint" includes several types, all of which yield an oil with the characteristic odor and flavor of this plant. The United States and Great Britain grow several horticultural varieties, and Germany and Russia grow varieties that have been variously designated. The two types that are grown commercially in the United States are called "common spearmint" and "Scotch spearmint". These may be confused with peppermint, but there are many differences in the characteristics of the plants and oils. Common spearmint has longer, lighter green leaves and slender, pointed flower spikes that are produced at the tips of the terminal and lateral branches, hence the term "spearmint". Scotch mint is more pubescent than either peppermint or common spearmint. It has green stems with the flowers borne in whorls in the leaf axils. It was introduced about 1910, and even though it is not as frost hardy as the common spearmint, it is grown almost exclusively in the spearmint areas of Michigan and Indiana because of its greater productivity and vigor.

FIG. 1. Peppermint (*Mentha piperita* L.) showing typical growth habit and leaves.

Oil of Japanese mint (*M. arvensis* var. *piperascens* Malinvaud) produces an oil that is often called "peppermint" but differs greatly from it, having a bitter, disagreeable taste that can not be removed completely by any known means. Japanese mint oil is very high in menthol, and this constituent can be removed by freezing. The dementholized oil contains from 40 to 50 percent menthol and

is sold in Europe for flavoring purposes. The Federal Food and Drug Act requires that all products flavored with Japanese mint oil and offered for sale in the United States be labelled " flavored with corn mint ", or " flavored with field mint ". The term " peppermint " can not be used for such products.

Many wild mints that have oils resembling both peppermint and spearmint are found along streams and in farm yards. These might be escapes from commercial plantings, but in most cases they yield inferior oils when distilled. It is a sound practice to eradicate all such native types before commercial production of mint oil is attempted.

The mints are perennial plants that may bloom extensively under some conditions, but, due to pollen abortion, the commercial types rarely set seed. They spread rapidly by means of surface and sub-surface stolons that may grow a distance of five feet or more during a season when conditions are optimum.

Cultural Requisites

It is the opinion of many people that the mints, in order to do well, must grow in a damp place, but this is an erroneous impression, for it has been found that the mints can be grown on a wide range of soil types and under varying conditions of moisture. It is generally agreed, however, that the soil should be deep, well-drained but not droughty, and of sufficiently loose texture to permit root growth and stolon elongation.

In Michigan and Indiana the mints are grown almost exclusively on highly organic soils, such as muck or peat. Mint is grown in the Yakima Valley area on a rich, deep volcanic ash that is slightly alkaline and on silt-loam and muck around Longview, Washington. The soil in the rest of the Columbia River District is an alluvial deposit that is high in organic matter. The soil in the Willamette Valley of Oregon is a deep, sandy river silt in some sections and a sandy loam in others.

FIG. 2. Planting mint by hand; the worker drops pieces of stolons into the furrow, steps on them and drags soil over them with his feet.

Although the mints are grown on soils covering a wide range of pH values, best production is found on mineral soils of a pH between 6.0 and 7.5 and on organic soils of a pH between 5.2 and 6.7.

The mints require an even distribution of rainfall throughout the growing season for the best results. In ditch-drained muck soils the water table should be maintained at about two feet where possible until just prior to cutting time when it is advisable to lower it to about three feet. Surface irrigation by means of open ditches or portable sprinklers is used extensively in the Northwest, and there is a trend toward the use of sprinklers in Michigan and Indiana.

Plantings in the Midwest must be protected from wind damage either by natural windbreaks or by planting willows or strips of rye at intervals through the field.

Land preparation for mint can be done in either fall or spring. Fall plowing, however, is not practiced in areas where the soil is apt to be flooded during winter and spring. It is necessary to use cultural practices before planting that will reduce the weed population as much as possible because weed eradication constitutes one of the biggest problems in mint production. Grasses are especially bad because they are very difficult to control, once the mint has begun to grow.

Commercial fertilizers are used by the better mint growers. Regular crop rotation programs are followed by progressive Michigan and Indiana growers, but western growers have not yet been confronted with production problems serious enough to necessitate rotation. Rotations include carrots, onions, corn and potatoes. Corn planted in hills immediately following the mint crop is the most satisfactory because the old mint can be eradicated by cultivation more easily. Mint is difficult to kill out in row crops such as carrots and onions.

Propagation

Mint is propagated vegetatively, using stolons or young plants obtained in spring from established plantings. Planting stock is raised by the producer or purchased from another grower. Fields that are set aside as a source of planting stock should be productive and disease-free. The stolons are lifted with potato diggers or plows and are shaken with pitchforks to remove excess soil. Planting stock should be used immediately or piled up and covered with soil to prevent dehydration.

A furrow-opener is used to make trenches four to six inches deep about three feet apart. These are laid off just ahead of the planters so that the soil is still moist when the stolons are dropped. Most stolons are planted by hand, although numerous planting machines have been tried. When planting by hand, a worker carries a sack of stolons on his back and drops the pieces end to end in the furrow. He steps directly on them to firm them in place and then drags soil over them with his feet. If additional covering is necessary, the field can be dragged after planting is completed. Stolons can be planted in either fall or spring, but the majority of growers favor spring planting.

An acre of good mint in organic soil should produce enough stolons to plant 10 to 15 acres, while in mineral soil an acre will produce stock for only three to five acres.

Young plants are used to start mint fields when for some reason the grower fails to get the field planted with stolons. Plants are obtained by pulling them in spring from established fields after they have reached a height of six to eight inches. They may be set with any of the conventional transplanting machines. Yields, however, from fields set with transplants are generally lower than from plantings established from stolons unless growing conditions are particularly favorable.

Control of weeds in mint fields is extremely important because their presence in the mint hay at distillation may discolor the oil and cause it to have a disagreeable odor and taste. New plantings are worked with spike-toothed harrows, weeders or rotary hoes. These implements can be used on mint until it is four to six inches tall with little deleterious effect. The areas between the rows are cultivated much the same as corn until the mint becomes too tall for mechanical equipment, after which weeds must be kept down by hand labor. At the present time no chemical weed control measures have proven satisfactory for mint.

Old mint plantings on organic soils should be plowed down to a depth of five to seven inches late in fall, but before any heavy freezes, in order to protect the stolons during winter. These older plantings are disked or harrowed in spring to smooth the field, some fertilizer should be added, and then the rotary hoe or weeder is run over the field as often as necessary to keep the weeds down. This operation is discontinued when the mint is about six inches tall; further weeding must be done by hand.

On the mineral soils of the Northwest the mint is plowed down in spring because winter killing is not a problem and much of the land is subject to flooding. The mat of stolons on the surface protects the land from erosion, and if silt is deposited by the flood, it can be plowed under. Weeders and harrows are used for cultivation in the Northwest also until the mint is six to eight inches tall; then hand weeding is necessary.

FIG. 3. Weeding mint by hand.

Diseases and Insect Pests

There are several diseases and insect pests of mint that can cause serious losses in some seasons. Anthracnose, caused by *Sphaceloma menthae* Jenkins, was serious at one time, especially in Ohio and Indiana. The symptoms are small, brown, sunken spots on young stems and leaves, and, as the affected plants mature, the lesions develop dark- or reddish-brown margins with light-gray centers. When the infection is serious, the lesions girdle the stems, killing the plants. Anthracnose can be controlled if all mint and mint refuse is carefully plowed under in fall. Mint that is thoroughly covered in this way rarely

produces the disease the next season, even though the stand was infected previously. The use of infected transplants instead of stolons tends to spread the disease.

Verticillium wilt, caused by *Verticillium* sp., has become increasingly serious in recent years in the Michigan-Indiana growing areas. Affected plants are dwarfed and may show one-sided growth. The young leaves may be bronze-colored, and as the season progresses the plants become yellow and die. Control of *Verticillium* wilt is difficult because the organism persists in the soil indefinitely. Development of wilt-resistant types and possible beneficial effect through irrigation show the most promise at the present time for controlling wilt.

Mint rust, caused by *Puccinia menthae* Arthur, is found in some seasons especially on spearmint but its effect is usually not serious.

Mint flea beetles, strawberry root weevils, black vine weevils, cutworms, grasshoppers and wireworms all attack mint. The mint flea beetle is especially damaging in Michigan and Indiana and in the Willamette Valley section of Oregon. The adults eat holes in the leaves and the larvae feed on the roots. Affected plants are reddish, stunted and often die. Sanitation and rotation give partial control, but the most effective means is to dust with calcium arsenate, DDT, or cryolite. These materials may be injurious to livestock, so the mint hay from treated fields should not be used for feed.

The black vine weevil and strawberry root weevil are especially troublesome in Oregon. The larvae attack the roots and the adults feed on the plants. The most effective control is obtained by scattering poison bran bait over the field. Grasshoppers, millepedes, cutworms and wireworms are usually of minor importance on mint.

Harvesting

No rule-of-thumb method for determining the proper time of harvest is reliable, and growers usually rely on past experience to determine the proper time to cut. The most satisfactory method for the Midwest is to run trial distillations when the mint appears to be about ready and then apply a test for free menthol, developed by Ellis, Swift and Thornton (4), that indicates the proper stage for harvesting. Under the arid growing conditions of the West Coast area, however, this test has not proven of value and mint is not harvested until it is in full flower.

Mint is cut with conventional mowing machines and left in the field until it is partially dried. It is then windrowed and, if necessary, allowed to dry further. Complete drying should be avoided because it results in heavy leaf loss during subsequent operations. Some drying is essential, however, because it makes the crop easier to handle and reduces distillation costs materially.

Mechanical choppers for loading mint in the field have been developed recently. The partially-dried hay is picked up from the windrow, chopped and blown into wagons or portable distillation tubs. This method makes it possible to process from one-fourth to one-third more material per tub of equivalent size than is possible when unchopped hay is used.

Distillation

The oils of peppermint and spearmint occur in minute glands that are found mainly on the undersides of the leaves. A limited number of glands is also present on the stems, stolons and upper surface of the leaves, but their effect on the yield of oil is negligible. The globules of oil are held in place by a thin membrane resembling very pliable cellophane, and the oil is not released until this membrane is ruptured.

Mint oils are removed from the plant by steam distillation. Stills generally consist of a boiler that carries at least 80 pounds pressure, two to eight galvanized sheet metal tubs or vats, a condenser for each tub, receivers or separa-

tors for collecting the oil, pumps for circulating the cooling water and hoists and hay forks for loading and unloading the tubs.

Stationary tubs are from six to 13 feet deep and six to eight feet across the top. They are tapered slightly from top to bottom to facilitate removal of " spent " charges. Either they are sunk in the ground or a work platform is built up around them. If a field chopper is not used, the partially-dried hay is loaded onto wagons and hauled to the still where it is lifted into the tubs with hay forks and mechanical hoists. It is steamed slightly and tramped down. A vapor-tight cover that is connected to a condenser is placed on the tub when it is filled completely. If choppers and portable tubs are used, the tub is filled in the field and brought to the still where it is connected to the steam line and the condenser.

When the tubs are thus ready, the steam is admitted at the bottom in such a way that it is spread out and permeates the whole " charge ". The increase in temperature ruptures the oil glands and vaporizes the oil by a process of hydrodiffusion. The mixture of vaporized oil and steam passes into the condenser where it is reduced to oil and water.

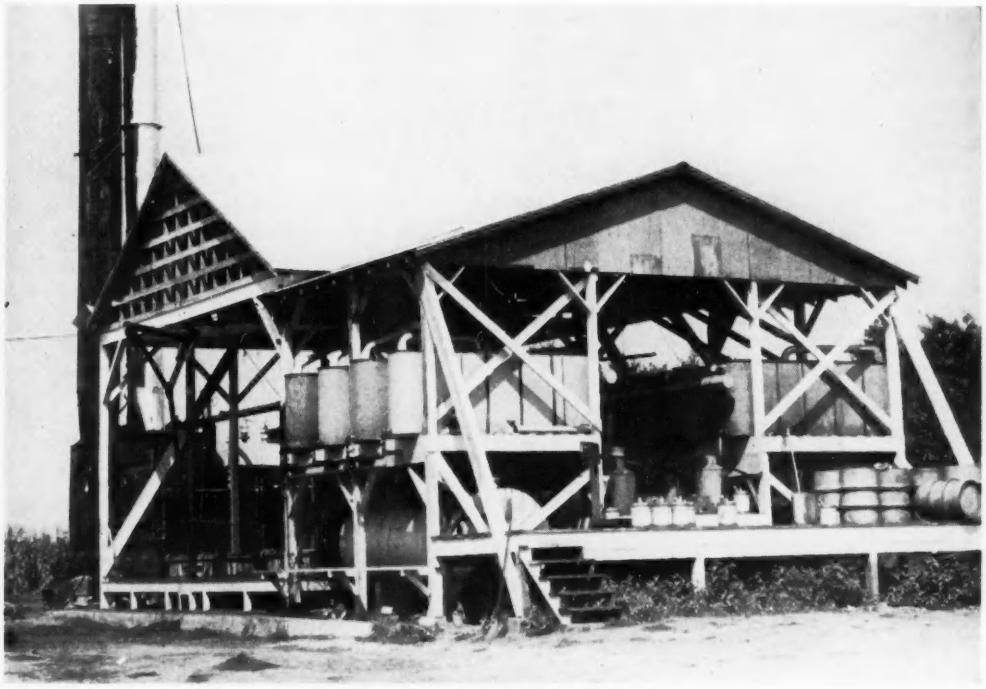

FIG. 4. A mint still: the mint " hay " is packed into the tubs that are sunk in the ground immediately in front of the boiler, the steam and oil vapors pass to the condensers (the galvanized tanks mounted above the platform on the left and right), the condensed oil and water flow into the receivers (one receiver is located directly behind the platform scales and two others may be seen directly across from it with pipes coming into them from the condensers), the oil is transferred from the receivers to the 5-gallon cans clustered about the platform scales, and eventually it is poured into the large drums at the lower right.

Several types of condensers are in use, but the most popular one consists of a worm of galvanized sheet metal pipe submerged in cold water in a large tank. Aluminum condensers are becoming increasingly popular and indications are that they will replace the galvanized type.

The mixture of oil and water flows

from the condenser into a receiver where the oil and water separate, the oil floating on the surface of the water. The receivers are patterned after a Florentine flask so that the water is drawn off at the bottom just fast enough to keep the receiver from running over.

A single distillation takes from 30 to 45 minutes, and when the operator decides that there is not enough oil coming over to make it worthwhile to continue the process, he stops the water flowing from the receiver, thereby causing the oil to rise to the top of the receiver and flow out through a spout into a suitable container.

Oil yields may vary greatly from year to year, depending on the growing season and the location. Yield per acre and production, as reported by the Bureau of Agricultural Economics of the United States Department of Agriculture, are given in Table 1. A progressive grower on good land in Indiana will produce 40 to 50 pounds of oil per acre, and in certain sections of the West, yields of 80 to 100 pounds per acre are not uncommon.

Spearmint in the Midwest produces more oil per acre on the average than peppermint, but this factor is off-set by the fact that peppermint oil normally commands a higher price, making possible a greater net return.

Farm prices of peppermint and spearmint oil have fluctuated over the years, but for certain periods they have remained more or less steady. The highest price occurred in December, 1925, when peppermint brought as much as $25.00 per pound. This probably resulted from the fact that two poor crops were produced the two preceding seasons and the shortage of oil caused a price inflation. The oil was so valuable at that time that many producers stored it in bank vaults and the odor of peppermint oil was very apparent in several banks in northern Indiana. The peppermint acreage was increased rapidly in the next few years with a consequent drop in price.

The lowest farm price for mint oil occurred in 1931 when it dropped to $1.19 per pound. The average price from 1929 to 1939 was $2.00 per pound. With the onset of World War II, the price began to increase again, averaging $5.00 to $7.00 per pound through the war years. The tendency is slightly downward at present with 1949 quotations at $3.50 to $5.00 per pound.

Mint oil is a stable product when stored in drums* or other containers that are well filled and adequately sealed. Oxidation takes place if air is admitted to a storage drum, forming a resin that must then be removed by redistillation. Upwards of 15 percent of the volume of the oil may be lost during this process.

The recognized standards on the analysis of mint oils are found in the United States Pharmacopoeia, and oils for use in medicinal products must meet these specifications. Oils for other purposes are often sold on U.S.P. standards, but much of the oil bought for confections and other flavoring uses is purchased by experienced buyers who recognize good oil by color, odor and taste. Samples of the oils may be used to make test batches of the product before the oil is accepted for purchase.

The bulk of the mint oil is purchased by a relatively small number of buyers who have representatives located in the producing areas. These dealers have facilities for blending, redistilling and packaging the oils before they are offered for sale to the consumer.

There is probably no limit to the land available for the production of mint oils, but the demand at present does not warrant excessive expansion. The pres-

* The term "drum" or "barrel" of mint oil usually refers to a galvanized container of 55 gallons capacity that weighs approximately 400 pounds when filled.

ent weakened market is largely due to a curtailment of purchases for export.

Literature Cited

1. Bacon, F. J. The botanic origin of American peppermint, *Mentha piperita* L. Jour. Am. Pharm. Assoc. **17**: 1094. 1928.
2. ———, *et al.* Studies on the genus Mentha. Jour. Am. Pharm. Assoc. **12**: 1075. 1923.
3. Bell, Jacob. Mitcham, its physic gardners and medicinal plants. Pharm. Jour. & Trans. **10**: 297. 1850–1851.
4. Ellis, N. K., *et al.* A method for telling the time of cutting peppermint for highest oil yield. Ind. Agr. Exp. Sta., Dept. Hort. Mimeo. 3, 3 pp. 1944 (Processed).
5. Gildemeister, E., and Hoffman, F. The volatile oils. Sec. Ed. 1913.
6. Hocking, G. M. Nomenclature of peppermint and its varieties. Jour. Am. Pharm. Assoc. **33**: 333–342. 1944.
7. McAlpine, A. N. Peppermint. Stand. Cyc. Agr. Vol. 9: 40. 1910.
8. Millspaugh, C. F. Medicinal plants. Vol. 2: 116. 1892.
9. Schürhoff, P. N. Cytologische und genetische Untersuchungen an *Mentha* und ihre Bedeutung fur die Pharmacognosie. Arch. Pharm. u. Ber. Itsch. Pharm. Ges. **267**: 515–526. 1929.

Utilization Abstract

Nipa Palm. The Nipa palm (*Nipa fruticans*) is unusual among palms in being truly aquatic, growing successfully, whether in the wild or where planted by man, only where its base is at least partially submerged in brackish water every day. It thus "lives in tidal marshes and on the shallowly submerged banks of bays and estuaries from the Philippines and Burma through Malaya to northern Australia and westward to Ceylon. . . . A single Nipa marsh in the Philippines has been estimated to contain more than 20,000 acres".

"The Nipa palm is of great local economic importance but its products seem not to have been exported in quantities to countries outside its range. Its principal use is to provide thatch for buildings and in many places this is the sole roofing material. In the large cities and towns of the Philippines its use for this purpose has been prohibited in recent years because it is highly inflammable. . . . The leaflets are also used extensively for matting, basketry, bags, raincoats, etc., and the dried petioles of the fronds have been used for fishnet floats, to float heavy timbers, and also as fuel. By cutting off the young fruit at the proper time the remaining stem can be made to yield a tremendous quantity of sweet juice for a period of 45 to 90 days by daily removal of a thin slice from the top of the stem that causes the sap to continue to flow. Since the fruiting season of the palms extends over quite a long period not all the palms in a given area are ready to be tapped at the same time and the season usually lasts for about six months. It has been estimated that in such a period a single acre of palms in the Philippines may yield 3,200 gallons of juice. The juice can be used for the production of sugar, alcohol, vinegar or for making native wine called 'toddy'. Since the palms occupy land of little value, require no maintenance care and can be tapped at low cost, they are believed to be the cheapest source of sugar and alcohol known, but seem not to have been exploited extensively for the former although in 1919 a production of two and a quarter million gallons of alcohol annually was reported produced from this source. The species is of sufficient importance that in some parts of the Philippines tidal marshes have been cleared of other vegetation and planted with Nipa palms, after which little or no cultivation has been required for their maintenance".

A few specimens of this palm have been successfully cultivated ornamentally at Georgetown, British Guiana, and in Coconut Grove, Florida. (H. F. Loomis, *Nat. Hort. Mag. 28: 4. 1949*).

SUGAR-CANE—*as Seen from Hawaii*

A native of the Old World, this large grass has become an important crop in many countries. It provides more than two-thirds of the world's annual sugar consumption of 37,000,000 tons.

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Early History

Only a few centuries ago sugar was an expensive luxury beyond the reach of all but the wealthy. Today sugar is firmly established in the diet of the occidental world as a staple which at normal prices supplies energy at a lower cost than any other food.

Cultivation of sugar-cane in India and Indonesia antedates recorded history. The western world first learned of sugar-cane during the campaigns of Alexander the Great. In 327 B.C. Nearchus, an officer in Alexander's army, wrote that the barbarians beyond the Indus were able without the help of bees to make honey from the sap of a " honey-bearing reed ".

Sugar-cane reached Spain by way of Egypt after the Moorish conquest of Spain in the eighth century. Some centuries later the Spaniards established sugar plantations in the Canary Islands. During the fifteenth century the Portuguese began to produce sugar in Madeira, the Azores and the Cape Verde Islands.

The discovery of the New World gave access to new areas for sugar production. On his second voyage in 1493 Columbus carried sugar-cane to Hispaniola, now Santo Domingo. Sugar-cane was subsequently carried to Mexico, Brazil, Peru, Cuba and Puerto Rico. It had been introduced much earlier by the Polynesians into the tropical islands of the Pacific. The end of the seventeenth century found sugar-cane well distributed throughout the tropical world. By the end of the eighteenth century a new era of sugar in abundance was within sight.

Sugar-Cane in Hawaii

Sugar-cane was already being grown as a food crop by the Polynesian inhabitants at the time of Captain James Cook's discovery of the Hawaiian Islands in 1778 (28). However, sugar-cane is not indigenous to Hawaii. It is believed that the Polynesians acquired their original stocks of cane from the Indonesian region in the course of their eastward migrations.

Sugar-cane was grown by the Polynesians not for sugar manufacture but for direct consumption. Sugar was first manufactured in Hawaii by an enterprising Chinese who in 1802 erected a crude mill equipped with stone rollers by means of which he extracted the juice from the sugar-cane stalks. This juice he then concentrated and crystallized by boiling in open pans in a manner still employed in maple-sugar making.

From this small beginning the sugar industry of Hawaii grew, at first haltingly and with many reverses, but after annexation by the United States in 1898, steadily and at an accelerated rate. By 1931 the annual production of raw sugar

[1] The writer acknowledges with thanks the aid of his colleagues in revising the manuscript and in supplying illustrations.

(96° basis) in Hawaii had risen to over a million tons.

World-wide over-production—or under-consumption—of sugar during the Depression years resulted in accumulating surpluses in the world market which led in 1934 to the enactment by Congress of the Jones-Costigan Sugar Act. This act established quotas for producers supplying the U. S. market. Curtailment of production under quota restriction continued until the beginning of World War II.

With the Japanese attack upon Pearl Harbor the problem in Hawaii became one of maintaining sugar production at the highest possible level while subordinating the manpower and materiel resources of the Hawaiian sugar industry to military requirements. Men and equipment were diverted to defense work. The Hawaiian sugar crop of 1942 declined to 870,000 tons. By 1945 it had dropped to 821,000 tons.

The industry is now recovering from its wartime disruptions, but production is still short of the million-ton level of the pre-quota years.

Taxonomy

The sugar-cane genus *Saccharum* L. and the rather closely related genera *Erianthus, Miscanthus, Sorghum* and *Imperata* are members of the sorghum tribe, Andropogoneae, of the Gramineae.

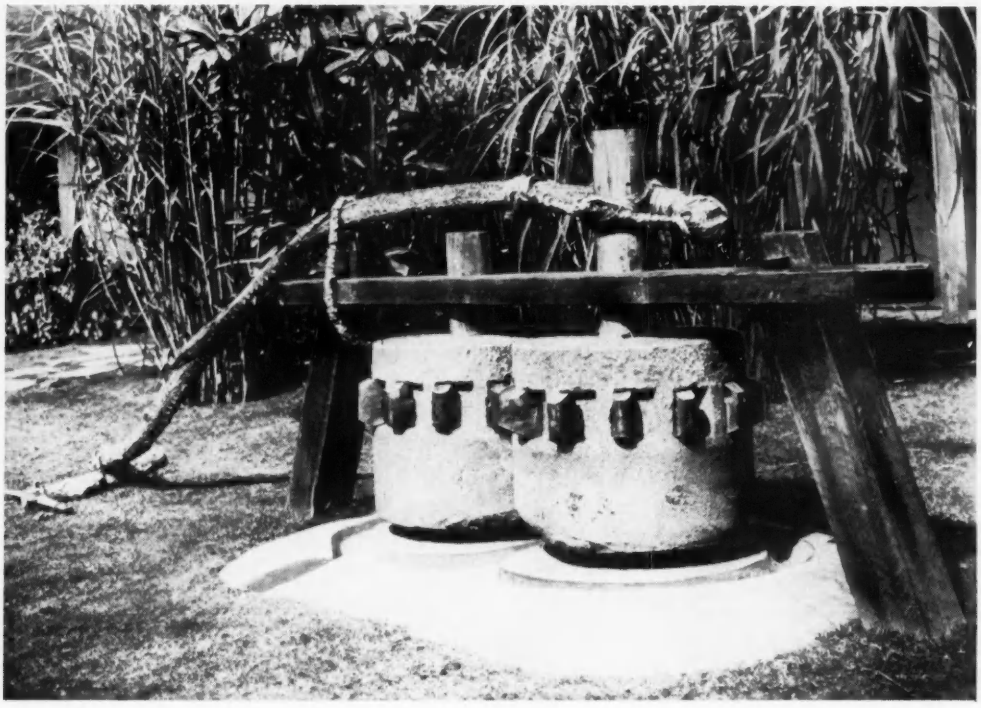

FIG. 1. Primitive animal-powered Chinese sugar mill with stone rollers fitted with wooden cogs.

The genus *Saccharum* comprises a group of perennial grasses ranging from slender wild forms only a few feet tall to large cultivated forms, the stalks of which may attain a length of 30 or more feet and a diameter of three inches or more.

Taxonomists have found it convenient to subdivide the genus *Saccharum* into

five species: *officinarum, sinense, Barberi, spontaneum* and *robustum* (20, 24). Several of these so-called species are far from homogeneous; they may be further subdivided into groups of varieties which differ in physical characteristics and sometimes in chromosome number from other groups within the species.

1. *S. officinarum* L. To this group belong the large-stalked, soft, sweet, juicy, cultivated varieties of the tropics referred to by the Dutch sugar-cane breeders as the "noble" canes. The prevailing chromosome number (2N) is 80.

2. *S. sinense* Roxb. Included in this group are several hardy, slender varieties which resemble each other in appearance and in being rather high in fiber and somewhat low in sucrose content. In southern China, where they are still cultivated to a limited extent, they are known as "bamboo"[2] canes, elsewhere as Chinese or Uba canes. The chromosome number of Kavangire, one of the varieties of this group, was reported by Bremer (10) to be 118 (2N).

3. *S. Barberi* Jeswiet. This species was named by Jeswiet (24) in honor of Dr. C. A. Barber who pioneered sugar-cane-breeding in India. It includes the hardy slender varieties originally cultivated in India which Barber himself had segregated into five fairly distinct groups (2). Bremer (11) finds the following chromosome numbers among the varieties included in this "species": 2N = 82, 90, 92, 107, 116 and 124.

4. *S. spontaneum* L. (Fig. 2). This group comprises a wide diversity of types, ranging from the extremely slender low-growing forms of higher latitudes to the tall vigorous forms of the tropics, some of which may attain a stalk diameter of one inch. All are feral, high in fiber and relatively low in sucrose, and all develop long rhizomes by means of which a single plant is able to spread aggressively over a large area. Representatives of this group are to be found in tropical Africa, Egypt, throughout southern Asia from Turkey to China, Taiwan, Japan, Philippines, Indonesia, New Guinea and several of the Oceanic islands. The following chromosome numbers have been reported among the various forms of this "species": 2N = 48, 50, 56, 60, 64, 72, 80, 96, 112, 120 and 128.

5. *S. robustum* (Brandes and Jeswiet) Grassl (20). Representatives of this species were collected in New Guinea in 1928 by an expedition which was led by Dr. E. W. Brandes and which included as members J. Jeswiet, formerly sugar-cane breeder at the Java Sugar Experiment Station, and C. E. Pemberton, entomologist of the Experiment Station, Hawaiian Sugar Planters' Association. *Robustum* and robustum-like forms have since been collected in New Britain and Lavongai (25) and in New Hebrides (20).

It seems probable that the wild canes collected in 1921 by van Harreveld in Celebes under the name "Tanangge" and by Asperslag in Borneo under the name "Teboe Salak" (7, 12) may be westerly representatives of the *robustum* group which appears to have its center of origin in New Guinea.

S. robustum is the largest and handsomest of the wild forms thus far discovered. In width and length of leaf, in stalk diameter, in tassel conformation and in general appearance it resembles the more slender noble varieties. However, unlike the latter, its stalks are hard, woody and low in sucrose content.

The following chromosome numbers have been determined for various clons of *S. robustum:* 2N = 60, 70, 80, 82, 84, 90, 96, 98, 100, 110, 116, 118, 140, 144, 148 (Bibliography 1, 7, 12, 29, 39).

[2] The "bamboo" canes of China are not to be confused with the White, Rose, Purple and Striped Bamboo of the tropics, all of which are varieties of *S. officinarum*.

The above classification at best is a crude one. For example, there appears to be little justification for lumping together under the name *S. Barberi* a heterogeneous group of Indian varieties, while at the same time excluding from this designation and assigning to a separate species, *S. sinense*, the so-called Chinese or Uba canes, which probably originated in India and which could be assigned to *S. Barberi* without materially aggravating the already marked heterogeneity of the *Barberi* group.

The *spontaneum* group is equally heterogeneous in type and in chromosome number. And in the New Guinea uplands, where *S. spontaneum* and *S. robustum* meet, there are populations which appear to be intermediate between these two species (25).

FIG. 2. Sugar cane growing wild in New Guinea. Left, *S. robustum;* right, *S. spontaneum.* (*Photo by C. E. Pemberton.*)

Fertile Hybrids

A remarkable feature of the genus *Saccharum* is the ease with which forms that differ widely in outward appearance and in chromosome number can be crossed to produce fertile hybrids (6, 8, 9, 22, 23, 30, 34, 36). This is true not only of crosses between different species of *Saccharum* but also of crosses between *Saccharum* and related genera. The explanation presumably lies in the high degree of polyploidy which characterizes the genus. In *Saccharum*, as in many other polyploid genera, once the minimum chromosomal complement needed to produce a functional zygote has been supplied, there is apparently considerable latitude in the number and assortment of chromosomes which may be added without impairing the viability, or even the fertility, of hybrids derived from wide crosses. This together with the fact that sugar-cane is wind-pollinated has undoubtedly favored interspecific and intergeneric miscegenation as a

factor in the evolution of *Saccharum*. It is not strange that taxonomists should find this genus a baffling one.

A Cytological Anomaly

A curious phenomenon, first reported by Bremer (6) and since confirmed by other cytologists (15, 23), occurs when the noble canes of the *S. officinarum* group (N = 40) are combined in crosses with *S. spontaneum* and certain other species as the male parent. When, for example, the Indian form of *S. spontaneum* (N = 32) is used as the pollen parent in crosses with the noble canes, the 2N number of the resulting hybrid is not 40 + 32 as expected but 40 + 40 + 32 (2N = 112). When the Java form of *S. spontaneum* (N = 56) is used as the pollen parent in crosses with the noble canes, the chromosome number of the resulting hybrid is not 40 + 56 as expected but 40 + 40 + 56 (2N = 136).

It is not yet clear whether the *spontaneum* gametes induce a doubling of the chromosome number of the *officinarum* egg cells with which they unite or whether they are able to produce viable hybrids only when they chance to unite with sporadically occurring diploid *officinarum* egg cells.

But this remarkable behavior goes even further. When, for example, the last named *officinarum-spontaneum* hybrid is used as a pollen parent (2N = 136, N = 68) and backcrossed to *officinarum*, the individuals in the resulting backcross population have not 40 + 68 chromosomes as expected but 40 + 40 + 68 (2N = 148). However, further backcrossing to *officinarum* results in no further increase in chromosome number but instead in individuals the chromosome numbers of which approximate the sum of the haploid numbers of the two parents.

It is to be hoped that the unanswered questions pertaining to this remarkable situation will enlist the further attention of cytologists.

Origin of the Native Varieties

Like most of our food crops, sugarcane is a heritage from the plant selectors of a bygone age. In our enthusiasm over the very considerable progress achieved through sugar-cane breeding during the past 50 years, it is easy to forget that what we have contributed is minor in comparison with the task accomplished by our prehistoric predecessors, that of developing from a useless wild grass with dry pithy stalks, such remarkable varieties as Bourbon, Cristalina and Yellow Caledonia, which until a few decades ago provided most of the cane-sugar that entered the world market.

Nothing is known with certainty as to the origin of these old native varieties. We know only that sugar-cane had been domesticated and was being cultivated by man long before the beginning of the Christian era. Thus far no form of *Saccharum* with juicy stalks high in sucrose has been found growing in the wild.

The meager evidence suggests two distinct centers of domestication, one in the New Guinea region and the other in India (3, 4, 5).

In outward appearance of stalks, leaves and inflorescence, certain forms of the wild *S. robustum* of New Guinea resemble rather closely some of the varieties of *S. officinarum* cultivated by the natives of New Guinea. The similarities between these two suggest a common ancestry.

In India several of the slender cultivated varieties of the *S. Barberi* group bear considerable resemblance in the outward appearance of their stalks and tassels to certain forms of *S. spontaneum* which grow wild in India. Here again the similarities between the two are suggestive.

In the related genus *Sorghum* a single gene difference determines whether the stalk will be dry and low in sugars or whether it will be juicy and sweet (21, 32). Because of the polyploid nature of

FIG. 3. Native varieties of the "noble" species, *S. officinarum,* in a New Guinea garden. (*Photo by C. E. Pemberton.*)

Saccharum, the situation in that genus may be somewhat more complex. On a parallel basis, however, not more than four loci would be required in the octoploid *robustum* and *officinarum* to produce an effect comparable to that achieved by a single gene difference in the diploid *Sorghum* species. The type of segregation for pithiness realized in backcrosses of *officinarum-robustum* hybrids to *S. officinarum* would seem to indicate that the difference in juiciness between these two species is determined by only a few major loci.

Renaissance of Sugar-Cane Breeding

Originally a home garden crop, sugar-cane, under the impact of European enterprise, became the basis of a large-scale plantation agriculture. This change altered the specifications to which a satisfactory variety must conform. Diseases which were of no importance in backyard plantings reached epidemic proportions when extensive areas were planted to a susceptible clon. It was such an epidemic in the 1880's that stimulated the renaissance of sugar-cane-breeding in Java (16). Other countries soon followed Java's lead.

To restore the disease-resistance and hardiness which the noble varieties had to some extent lost in the course of their domestication, the breeders turned first to the more primitive slender Indian varieties and subsequently to the wild species. The important varieties of the world today have been derived almost without exception from crosses between the soft sweet noble canes and the hardy primitive or wild canes, usually followed by one or more backcrossings of the hybrid to the noble varieties.

The Inflorescence

The sugar-cane inflorescence, a graceful silky panicle, is referred to in some of the British possessions as an "arrow" and in Hawaii as a "tassel". The tassels of the slender *spontaneum* and *Barberi* canes are small, sometimes scarcely a foot in length, with simple short side branches. The tassels of the *robustum* group are considerably larger. The largest most complexly branched tassels are to be found among the *officinarum* canes and their derivatives; their tassels may exceed two feet in length.

Each tassel bears many small spikelets which are arranged in pairs on the branches. The number of spikelets per tassel ranges from hundreds in the smaller *spontaneum* tassels to thousands in the larger *officinarum* tassels.

Each spikelet contains a perfect (bisexual) flower provided with three anthers and a single ovary surmounted by two plume-like stigmas. The sugar-cane spikelet and its component parts are considerably smaller than those of the closely related sorghum. Unlike sorghum, each sugar-cane spikelet is subtended by a whorl of long silky hairs which spread out to enable the seed to float in the air for wind dissemination.

For such a large grass, sugar-cane has extremely small seeds. A sugar-cane seed of average size weighs about one one-hundredth as much as a grain of wheat which it resembles in miniature.

Flowering in Relation to Day Length

In a majority of both cultivated and wild forms of sugar-cane the growing point changes to a flower primordium only under the influence of short days—or long nights. In the northern hemisphere flower bud differentiation in sugar-cane occurs from August to October. The tassels emerge from October to January. In the southern hemisphere flower bud differentiation occurs from February to April and tassel emergence from April to July.

Some of the wild canes indigenous to higher latitudes are exceptions to this

rule; they require a long day for flowering. When taken to the tropics they fail to flower, presumably because the maximum tropical day length is shorter than that which they require for floral initiation.

It appears that each variety has its particular day-length range within which floral initiation may occur, provided other factors, such as stage of development and nutritional status, are favorable. In some varieties this range is a wide one, resulting in abundant flowering over a considerable period. Certain other varieties appear to be able to differentiate flower primordia only within a narrow and precise day-length range.

The agronomist looks upon tasseling in sugar-cane as a dissipation of energy which might better be devoted to the storage of sucrose in the stalk. To the sugar-cane-breeder tasseling is indispensable. The breeder needs a positive means of inducing flowering at will to enable him to synchronize the early and late flowering varieties and thus to facilitate crosses between them. He would like to be able to force the reluctant tasselers to flower in order to use them as parents in breeding toward freedom from tasseling. He looks enviously at the techniques which his colleagues have developed for inducing flowering in pineapples (13, 35). Unfortunately sugar-

FIG. 4. Sugar cane in tassel. In the northern hemisphere flowering occurs in October, November and December; in the southern hemisphere in April, May and June.

cane has thus far failed to respond to the acetylene, ethylene and alpha-napthaleneacetic acid treatments which are so effective in inducing floral initiation in pineapples.

Recent studies by G. O. Burr (unpublished) have shown that tasseling can be prevented by interrupting the night "rest period" with artificial illumination. An investigation of the economics of utilizing this procedure for prevention of tasseling on a field scale is now under way.

Artificial illumination at the beginning of the floral initiation season may offer the breeder a means of delaying the tasseling of early flowering varieties to facilitate crossing them with late tasseling varieties.

Investigations in Formosa (33) have shown that the photoperiodic response is localized in the young unfurling and newly unfurled leaves. Flowering has been delayed for several weeks by a single trimming of these young leaves shortly before flower bud differentiation occurred. Tasseling has been prevented by repeatedly trimming off the young leaves during the season of differentiation. Leaf trimming thus offers still another possible means of delaying the flowering of the early tasselers.

Assembling of Breeding Material

It is not yet within the power of the breeder to create new and useful genes at will; he must content himself with developing new combinations of the already existing genes in his collection of breeding material. Thus the success of his breeding project will be determined in part by the comprehensiveness of his breeding collection.

The task of assembling representative samples of the sugar-cane germ plasms of the world is still far from complete. The Java Sugar Experiment Station has pioneered in this field; until the outbreak of World War II its breeding collection was outstanding. Under the leadership of Dr. E. W. Brandes, the Division of Sugar Plant Investigations of the USDA has made expeditions to many of the regions where sugar-cane is indigenous and has assembled a large collection which is being drawn upon by sugar-cane breeders throughout the world. The Hawaiian Sugar Planters' Association has fostered collecting expeditions to New Guinea and neighboring regions.

Among the regions which have not yet been adequately explored for their resources of sugar-cane germ plasm are Burma, Siam, Indo-China, Borneo and Dutch New Guinea.

In the importation of breeding material, consideration must be given to the danger of introducing foreign diseases and insects. The Division of Sugar Plant Investigations maintains at Beltsville, Md., a quarantine greenhouse where new acquisitions are kept under observation for a one-year period before release. Before being planted in the quarantine house, the imported cuttings receive a hot-water treatment at 52° C for 20 minutes. This treatment is lethal to insects and provides an effective control for several but not all of the systematic diseases of sugar-cane.

The Hawaiian Sugar Planters' Association maintains a quarantine greenhouse on Molokai, an island on which there are no sugar plantations. At this station varieties introduced from abroad are kept under observation for one year in an insect-proof quarantine greenhouse, and for a second year in a quarantine field. The hot-water treatment is applied to cuttings upon receipt and to each succeeding vegetative generation thereafter until the variety is finally released.

It is recognized that even these precautions cannot preclude the possibility of a disease gaining entrance in a symptomless, tolerant variety, the sugar-cane

counterpart of a Typhoid Mary. This calculated risk is assumed under the conviction that the gains to be realized through the introduction of breeding material outweigh the risk of possible loss.

Crossing Technique

The spikelets of sugar-cane are so small and delicate that manual emasculation is not feasible, nor has hot-water emasculation (31) given consistent results. Male sterility, however, is common, and of the varieties which produce pollen in abundance, many are moderately to highly self-sterile.

Prior to 1925 crossing in Hawaii was accomplished by cutting one or more tassels of the variety that was to serve as the male parent, placing them in a vase of water and supporting them in position around the female tassel which was left standing in the field. Since the progression of blooming from the tip downward to the base of the tassel requires five to ten days, and since fresh male tassels had to be supplied daily, this method was time-consuming. Moreover, there is always a shortage of tassels of the sparse tasseling varieties most sought after when breeding for freedom from tasseling.

In 1925 Verret and his colleagues (38) discovered that addition of sulphur dioxide to the water helped to keep the male tassels alive. Further studies proved the sulphur dioxide solution to be so effective that even the female tassels could be cut and kept alive for the 20 to 30 days required to ripen the seed. It thus became possible to cut both female and male tassels and set up the cross in an area well isolated from possible contamination by wind-borne pollen.

FIG. 5. Collecting tassels of sugar-cane for use in crossing. Each tassel bears an identifying tag.

FIG. 6. Crossing rack. The female tassels are surrounded by tassels of the male parent. A weak solution of sulphurous and phosphoric acids helps to keep the tassels alive.

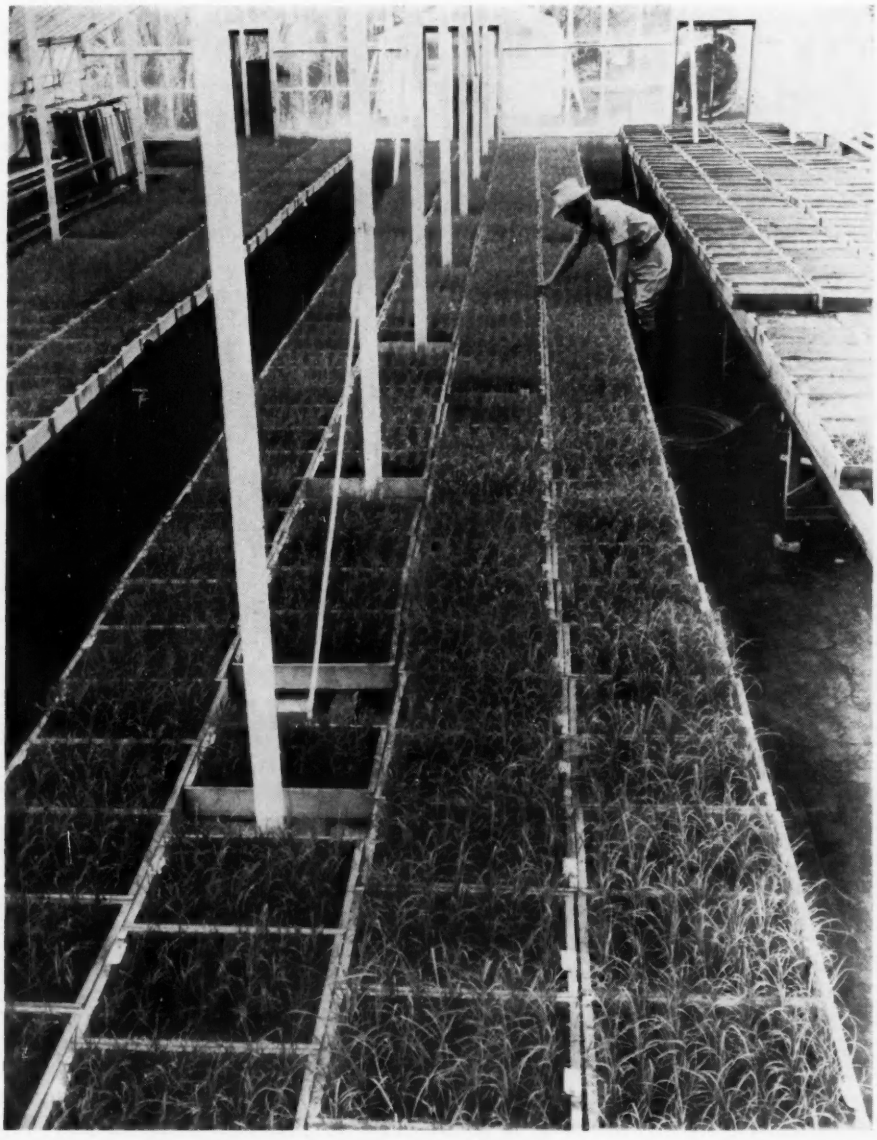

FIG. 7. Month-old hybrid sugar-cane seedlings grown from the seed. The leading commercial varieties of Hawaii all began their careers as diminutive seedlings in this greenhouse.

It was subsequently found that addition of phosphoric acid to the solution further increased its effectiveness. The present standard solution contains 0.015 percent of SO_2 and 0.0085 percent of H_3PO_4 in tap water.

Many other acids, including hydrochloric, sulphuric, nitric and formic, in dilutions in tap water of 250 ppm or thereabouts to give a pH of 2.7 to 3.0, have the effect of promoting the uptake of water by the cut stalk and of maintaining the turgidity of the tassel. Of the many combinations tested, the sul-

FIG. 8. Juice-sampling punch and hand refractometer. A composite juice sample is drawn from ten or more stalks. The refractometer reads the percentage of solids in solution on a sucrose scale.

phurous-phosphoric solution in the proportions indicated has proved most effective. The nature of the action of these acidulated solutions in maintaining turgidity is not understood; the problem is one which might well merit the attention of physiologists.

Experience has shown that the tassels are less likely to die prematurely if cut with two or three feet of mature stalk. The strength of the solution in the vase must be maintained by replacing it with fresh solution every two or three days.

The cut tassels of some varieties die prematurely in the standard solution. When such varieties are to be used as female parents, the tassels may be allowed to remain standing in the field surrounded by cut tassels of the male parent placed in the solution. Another

alternative, developed in India (37), consists of layering the female stalk several weeks in advance of flowering. When the layer is sufficiently well rooted, the stalk is cut below the layer and removed to an isolated crossing rack, the layer being kept moist by daily watering until the seed has matured.

These developments in crossing technique have increased substantially the number of crosses which can be made during the six-week tasseling period. The magnitude of the breeding program is no longer limited by the number of seedlings that can be propagated each year but rather by the number that can be adequately evaluated in field trials.

Breeding

Sugar-cane, like maize, is typically anemophilous; on a still morning the tassels of a pollen-fertile variety when shaken release a cloud of pollen which floats in the air like fog. In the pollen-sterile and self-sterile forms, cross-fertilization is of course obligatory.

Sugar-cane evidences the usual reaction of naturally cross-fertilized organisms to inbreeding; populations grown from selfed tassels showed a marked loss of vigor. Since sugar-cane can readily be propagated asexually, it is not necessary to resort to selfing, as in maize, to perpetuate a given genotype. Selfing prior to crossing therefore offers no distinct advantages in sugar-cane breeding. It is unlikely that the maize breeders would have resorted to the use of inbred lines were it possible and economically feasible to propagate maize asexually.

Leading sugar-cane varieties of the world today are complex hybrids synthesized by bringing together a diversity of genotypes, both cultivated and wild. The pedigrees of modern varieties evidence a lively exchange of breeding material between the various countries engaged in sugar-cane breeding.

The objective in sugar-cane breeding is to develop varieties which are able to produce sugar at a lower cost. An effective way of reducing production costs is to increase the yield of sugar per unit of time and area.

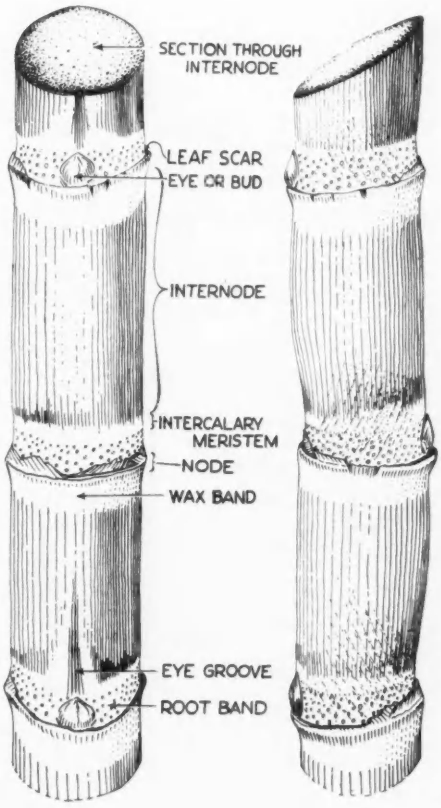

FIG. 9. A typical "three-eye" cutting.

Components of sugar yield are tonnage of cane and percentage of sucrose in the cane. It is less difficult to improve cane tonnage than to improve sucrose content; the sharply skewed distribution curve for sucrose content in a population of varieties suggests that some physiological barrier tends to hold the sucrose content of the juice below a certain maximum.

Since diseases can depress both cane tonnage and sucrose content, resistance to diseases is of major importance. The same may be said of the ability of the stalks to carry through to harvest in

sound condition. Where damage from insects is serious, resistance to these pests becomes important. Some varieties fail to ratoon vigorously after harvesting and for that reason must be discarded. "Toughness", the ability of the stalk to lodge without fracturing at the base, and freedom from tasseling are desiderata under two-year cropping in Hawaii. For harvesting with machines of the type employed in Louisiana, an erect growth habit is desired. Where the crop is still being harvested with a cane knife, varieties with thick stalks are preferred to slender varieties.

The hand refractometer provides a quick and easy means of measuring the sucrose content of each of the thousands of seedlings in preliminary trials. By means of a simple sampling punch, a composite juice sample is drawn from ten or more representative stalks in a plot. The refractometer scale is calibrated to read the percentage of sucrose in the sample.

FIG. 10. Cuttings bundled for transportation to the planting field. The ends of the cuttings are sprayed with an organic mercury solution to prevent invasion by micro-organisms. (*Photo Hawaii.*)

In the more advanced yield trials the cane from each plot is ground separately at the factory, and the sucrose content of the resulting juice sample is determined by a polariscope reading.

Agronomy

CLIMATIC REQUIREMENTS. The specifications for an ideal climate for produc-

tion of sugar from sugar-cane might read somewhat as follows:

(*a*) A long, warm summer growing season with adequate rainfall.

(*b*) A fairly dry, sunny and cool but frost-free ripening and harvesting season.

(*c*) Freedom from typhoons and hurricanes.

These specifications are seldom realized in their entirety. Therefore, a major objective in sugar-cane-breeding is to develop varieties which are better able to cope with climatic shortcomings.

Because the sugar-cane plant grows rather slowly during the early months of its life, a long growing season is essential to high yields. Sugar-cane areas that lie outside the tropics are handicapped by the shortness of the growing season and by the necessity of completing the harvest before the onset of freezing temperatures which would render the cane unfit for milling.

In most countries the sugar-cane crop is started during the fall, winter and spring months, and harvested the following winter and spring at 11 to 16 months of age. In Hawaii, however, crop lengths range from 18 months at the lower elevations to as long as 30 or more months at elevations of 2000 feet and higher. There are several reasons for Hawaii's long cropping practice. The summer months are relatively cool with mean temperatures of 74° to 78° F. Temperatures during the winter months are only five to eight degrees lower than in summer. In the absence of sharply defined seasons it is possible to extend the planting and harvesting operations over a long period and thus to provide year-round work for employees.

FIG. 11. Planting machine with covering device detached to show placement of cuttings and fertilizer. (*Photo by R. H. Lodge.*)

Besides being somewhat cool for sugar-cane, particularly at the higher elevations, the climate of Hawaii falls short of perfection in that the summer months,

when the demand of the cane plant for moisture is greatest, are the months of lowest rainfall. Except in certain rainy districts, rainfall must be supplemented with irrigation, particularly during the dry summer months.

PLANTING MATERIAL. Since the cultivated varieties of sugar-cane are highly heterozygous, they do not "come true" from the seed produced in their tassels. For commercial plantings cuttings of selected varieties are used. Variously referred to in different sugar-cane regions as "setts", "points", "seedpieces" or merely as "seed", these cuttings consist of sections of the stalk, ranging in length from the short single-eye pregerminated cuttings of Java to the entire stalk, four feet or more in length, of Louisiana. The cuttings employed in the different districts of Hawaii range from one to three feet in length.

"Top" cuttings from the upper portion of the mature stalk germinate faster and with fewer "misses" than do cuttings from the older basal portion of the stalk, the eyes of which have become hardened from long exposure (14).

FIG. 12. A good stand of sugar cane at ten months of age.

Disinfection of the cut ends of the seedpieces by dipping in a solution of an organic mercurial provides protection against invasion by soil-borne organisms which might otherwise destroy the pieces before the new shoots can establish themselves (17, 27). The benefits of the treatment are most marked when the seed cane is too succulent or when planted under conditions which are too cold, too wet or too dry for satisfactory germination.

SOIL PREPARATION AND PLANTING. Preparation of the soil for planting may consist of nothing more than digging a hole for the cutting. Such is sometimes the practice in the newly cleared lands of Cuba (19). At the other extreme, soil preparation may include deep subsoiling followed by repeated plowing and harrowing with heavy tractor-drawn equipment.

In arid districts the cuttings are planted in the bottoms of furrows which have been laid out to serve as channels for irrigation. In swampy areas, on the other hand, it is sometimes necessary to construct raised beds or "grand-banks" to raise the level of the seed bed above that of the water table to provide soil aeration and drainage.

Planting may be done by hand or by a mechanical planter mounted usually on a crawler tractor. The mechanical planter makes the planting furrows, applies fertilizer, places the cuttings in the furrow and covers them with soil in a single operation. In mechanical planting the cuttings are placed horizontally in the furrow, usually end to end, and covered with an inch or two of soil. In planting by hand the cuttings may be placed at an angle inclining toward the vertical with the top end of the cutting at or near the surface of the seed bed.

GROWTH CHARACTERISTICS. The growth curve of sugar-cane contrasts sharply with that of maize or sorghum. At two

months from planting a field of maize will be head-high or taller, while a field of sugar-cane of the same age will be scarcely more than knee-high. The growth curve of sugar-cane however, continues to climb until it passes the "boom" stage at six to ten months of age. The growth rate eventually declines but under favorable conditions a sugar-cane stalk may continue to elongate for three or more years.

ence in yield at harvest. Close planting is generally favored, however, because it makes for faster "closing in".

RATOONING. Like many other perennial grasses, sugar-cane is able to produce successive crops from stubble. These "ratoon" crops grow from the buds of the underground portion of the stool left undisturbed in the harvesting of the preceding crop. Ratoon crops usually get under way more quickly and

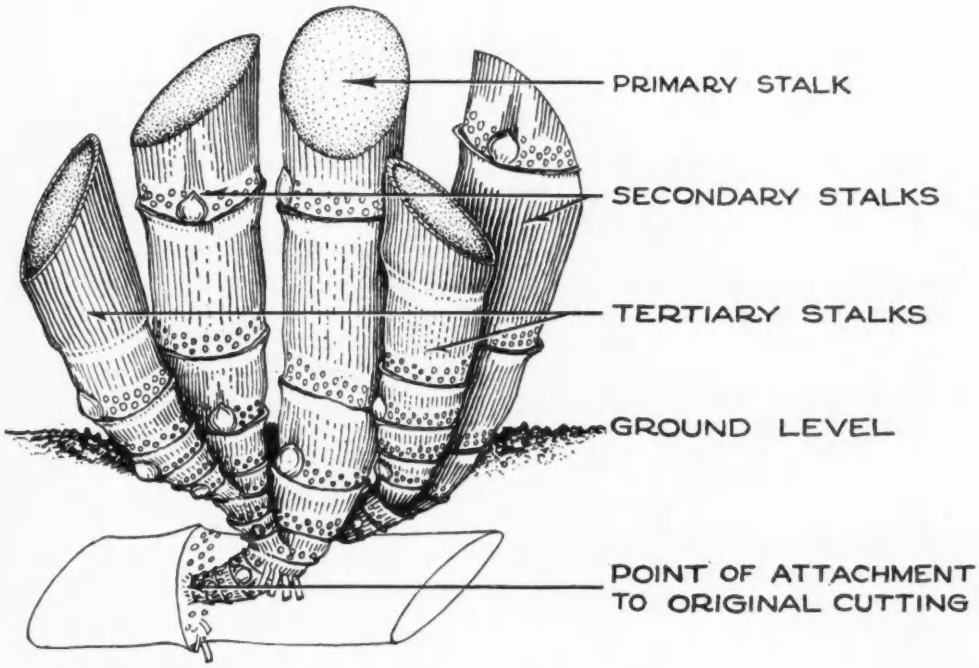

FIG. 13. Base of a sugar cane stool. In practice the stalks are cut at or near the soil surface. Ratoon shoots develop from underground buds.

Sugar-cane is remarkable in its capacity for tillering. Tillering is related to stalk diameter; the slender varieties tend to tiller more freely than do those with thick stalks. As a rule more shoots develop per unit of area than can be maintained under the prevailing soil and climatic limitations. In the ensuing competition the weaker shoots succumb, Replicated tests of close planting (cuttings placed end to end) versus wide spacing (cuttings spaced three or four feet apart) have shown but little difference in yield at harvest. Close planting is generally favored, however, because it makes for faster "closing in".

RATOONING. Like many other perennial grasses, sugar-cane is able to produce successive crops from stubble. These "ratoon" crops grow from the buds of the underground portion of the stool left undisturbed in the harvesting of the preceding crop. Ratoon crops usually get under way more quickly and "close in" more rapidly than plant crops started at the same time.

Under favorable conditions good yields have been realized from as many as 20 or more successive ratoon crops. This, however, is exceptional. Many soils suffer a progressive loss of tilth and aeration accompanied by declining yields in successive ratoons. Generally one "plant" crop followed by one, two or three ratoon crops constitutes a cycle.

No ratoon crops are grown in Java due to an agrarian policy which requires

FIG. 14. Concrete irrigation flume with discharge opening and metal gate at each furrow. In fields equipped with this type of flume one man may irrigate 15 acres or more in an eight-hour day. (*Photo by R. H. Lodge.*)

that the land be returned to rice and other native food crops immediately following the harvesting of the sugar-cane "plant" crop.

CULTIVATION. The principal objective in cultivation is weed control. In regions of low-cost labor this may be accomplished with a hoe or its equivalent.

In Hawaii and elsewhere high wage rates have necessitated more and more mechanization.

A few years ago weed control in Hawaiian cane fields was accomplished chiefly by means of tractor-drawn cultivating implements of various types. Recently these have largely given way to herbicides applied as sprays from knapsack tanks, from tractors and from airplanes and helicopters.

IRRIGATION. An annual rainfall of 60 inches, if well distributed, and if other factors are favorable, will produce a good crop of sugar-cane. In areas of low rainfall recourse must be had to irrigation. In Hawaii slightly more than half of the 210,000 acres under sugar-cane is irrigated. Much of the unirrigated acreage is situated in districts which receive abundant rainfall.

Several labor-saving types of flumes have been devised to facilitate distribution of water to the irrigation furrows. In fields so equipped the area covered by a single irrigator during an eight-hour working day may exceed 15 acres.

The interval between irrigations ranges from seven to 30 or more days, according to soil type, stage of growth of the crop, temperature and precipitation.

FERTILIZER REQUIREMENTS. Fertilization practices are too local and varied to permit generalization. For maximum yields most soils require applications of nitrogenous fertilizers in amounts ranging from 40 pounds of nitrogen per acre for crops of less than 12 months, as in Louisiana, to 200 pounds or more of nitrogen per acre for two-year crops in some districts of Hawaii.

Phosphoric acid and potash requirements vary even more, some soils being abundantly supplied with both, while others are deficient in one or both. In practice the amounts of P_2O_5 and K_2O applied for two-year crops in Hawaii range from 0 to 250 pounds per acre.

Occasional instances of response to applications of the trace elements have been reported. Manganese and iron deficiency symptoms have been observed on several plantations in Hawaii. Sugar-cane grown on the peat soils of the Florida Everglades has shown response to small applications of zinc, copper and manganese.

A variety of methods is employed in different regions to estimate the N, P and K requirements of the sugar-cane crop. Included in the list are field trials of many types, soil analyses by several methods, plant tissue analyses, foliar diagnoses and the use of indicator plants in field microplots and in pot tests. Each of these methods has its advantages and shortcomings.

Diseases and Pests

DISEASES. The major sugar-cane diseases of the world have been listed by Martin (26) as follows:

	Causal Organism
Bacterial Diseases	
Leaf scald	*Bacterium albilineans* Ashby
Gumming disease	*Xanthomonas vascularum* (Cobb) Dowson
Fungus Diseases	
Smut	*Ustilago scitaminea* Syd.
Downey mildew	*Sclerospora sacchari* Miy.
Virus Diseases	
Streak	A virus transmitted by the leaf hopper, *Balclutha mbila*
Fiji disease	A virus transmitted by leaf hoppers of the genus *Perkinsiella*
Mosaic	A virus transmitted by *Aphis maidis* and other aphids
Unclassified	
Serch disease	Cause unknown

Of these, only mosaic and leaf scald occur in Hawaii.

There are many other sugar-cane diseases which have at one time or another been responsible for serious losses in various parts of the world. When extensive areas are planted to a single geno-

type, such as an asexually propagated clon, the stage is set for possible disease epidemics. On the other side of the ledger, disease epidemics may be credited with having stimulated in many countries the initiation of breeding programs that have resulted in the development of disease-resistant varieties which at the same time are capable of producing higher yields. Throughout the sugar-cane world such disease control as is being achieved rests for the most part upon the replacement of the older susceptible varieties with new varieties which have been bred for disease resistance.

INSECT PESTS. During the early years of the present century the Hawaiian sugar industry was all but ruined when a leaf hopper (*Perkinsiella saccharicida*) somehow gained entrance, possibly in a shipment of cuttings from Australia. In the absence of its natural enemies this leaf hopper multiplied at a prodigious rate. The industry was saved from extinction only by the prompt introduction of parasites collected in regions where this leaf hopper is indigenous.

According to C. E. Pemberton, over 200 species of insects which attack sugar-cane in various parts of the world have been recorded in the literature. A list of the more important ones would include the lepidopterous top borers, several army worms, the beetle stalk borer, several species of leaf hoppers, frog hoppers, aphids, mealy bugs and the coleopterous root-attacking grubs, weevils and wire worms.

Because of the impenetrable nature of a mature stand of sugar-cane it is practically impossible to apply insecticides except by plane. The Hawaiian sugar industry has placed its reliance upon biological control, and its efforts in this direction have met with outstanding success (40). At present every major insect pest of sugar-cane in Hawaii is being satisfactorily controlled by insect parasites which have been introduced for that purpose.

OTHER PESTS. Rats find the sugar-cane stalk an attractive food and at times cause serious damage to the crop. In Hawaii rats are controlled by means of a " prebait " system of poisoning (18). Feeding stations placed at intervals along paths and field boundaries are kept supplied for a ten-day period with unpoisoned rolled oats. By the end of that period most of the rat population in the field will have become regular customers at the feeding stations. The unpoisoned bait is then replaced with rolled oats poisoned either with thallium sulphate or with zinc phosphide. Both poisons are highly effective and may be used alternately. Prebaiting and poisoning are repeated at intervals of three to four months.

Other countries have reported instances of damage to sugar-cane by cockatoos, bandicoots, foxes, jackals, wild pigs, deer and wild elephants.

Ripening and Harvesting

RIPENING. Maximum yields can be realized only if the crop is well ripened before harvest. The first requirement for ripening is a retardation of the growth rate. Low temperatures, moderate drought and nitrogen starvation are effective ripening agents. As the growth rate declines, less of the sugar which is manufactured each day by the leaves is expended in building new tissues. Thus a larger proportion goes into storage in the stalk. Moreover, low temperatures and moderate drought promote the condensation into sucrose of the glucose and fructose which are present in considerable amounts in the immature portion of the stalk. As ripening proceeds, the percentage of sucrose in the stalk gradually increases while the percentage of reducing sugars diminishes.

Of the several factors which may act to retard growth and thus to induce ripening, none is more effective than low temperature. A prolonged period of cool weather will retard growth and improve

sucrose content even when the crop is amply supplied with nitrogen and soil moisture. The return of warm weather will, in the absence of other limiting factors, such as drought or nitrogen deficiency, bring about a resumption of rapid growth, a rise in reducing sugars and a decline in the percentage of recoverable sucrose. Similarly the replenishing of soil moisture through rainfall or irrigation in a crop which has ripened under the influence of drought will, in the absence of other limiting factors, induce a resumption of growth and a return to an unripe condition.

FIG. 15. A two-year-old field ready for harvest.

HARVESTING AND TRANSPORTATION.

Most of the world's sugar-cane still is being harvested with a cane knife. In Louisiana and Hawaii high wage rates have necessitated mechanization. The problem of developing an effective harvesting machine for Hawaiian conditions is a difficult one. The two-year-old crop presents a mat of tangled stalks with yields often in excess of 100 tons per acre. However, considerable progress has been made by the agricultural engineers, and improved models are now undergoing field trials.

The manner of transport is determined by local conditions. In the tidewater plantations of British Guiana the cane goes to the mill in small barges by way of canals provided for that purpose. In the Caribbean islands ox carts are still widely used to haul the cane from the field to the railroad. On some Hawaiian plantations small railroad cars are taken directly into the harvesting field on temporary "portable" tracks. In the rainy Hilo district of Hawaii much of the cane

is transported from the harvesting field down the slope to the mill in flumes. In the drier districts large trucks carrying from eight to 25 tons of cane are gradually replacing other means of transport.

The mean yields for Hawaii in 1948 were 75 tons of cane and 8.35 tons of sugar (96 degree) per acre. Since the average age at harvest is about 24 months, these yields correspond approxi-

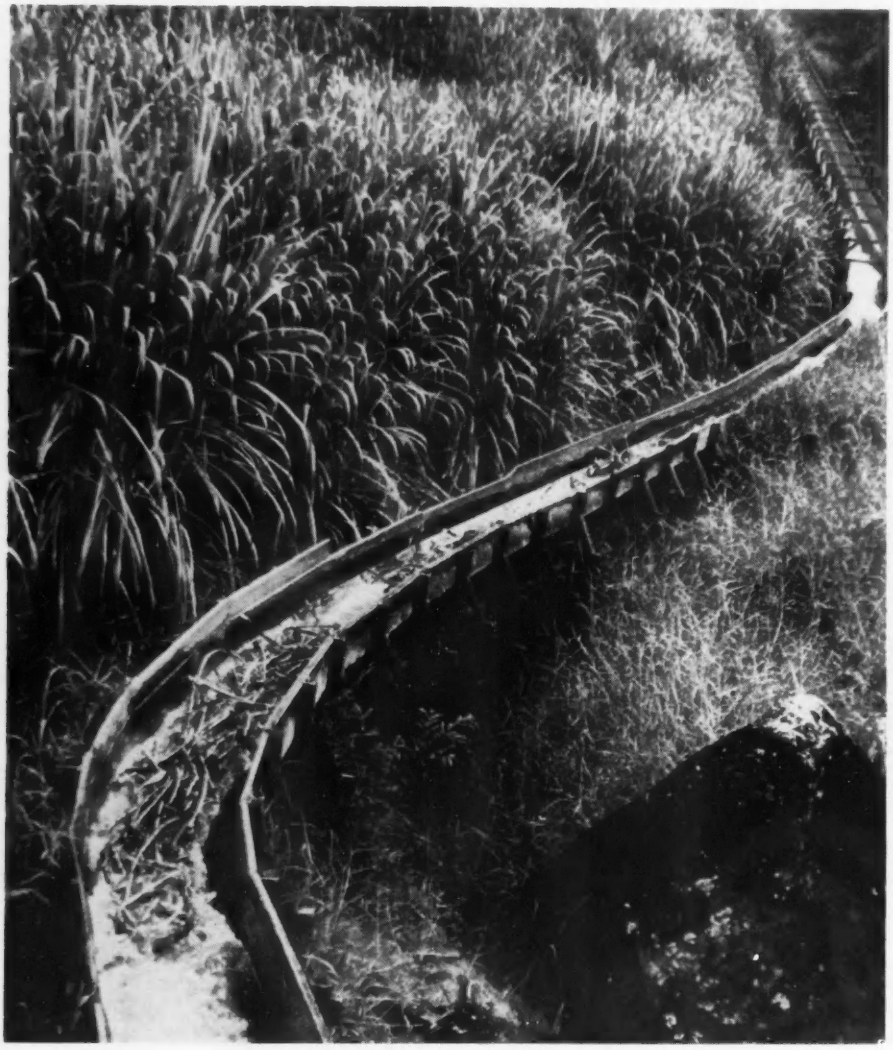

FIG. 16. Flume transportation of cane from harvesting field to mill.

YIELDS. Because the age of the crop at harvest varies so widely yield comparisons between different regions may have little meaning unless reduced to a common denominator such as tonnage of cane (or sugar) per acre-month.

mately to three tons of cane and one-third of a ton of sugar per acre-month.

Individual fields under particularly favorable conditions have produced yields in excess of 150 tons of cane and 18 tons of sugar per acre, corresponding to over

six tons of cane and three-quarters of a ton of sugar per acre-month.

Processing

MAKING RAW SUGAR. The making of raw sugar from sugar-cane consists essentially of four steps:

(*a*) The juice is expressed by passing the cane between heavy steel rollers under high pressure.

The fiber (bagasse) which remains after the juice has been expressed is carried by conveyor to the furnaces where it is used as fuel to supply the power needed to operate the factory. The percentage of bagasse (dry basis) in the cane ranges from eight to 16.

The number of tons of cane required to produce one ton of raw sugar depends upon the sucrose content of the cane. In

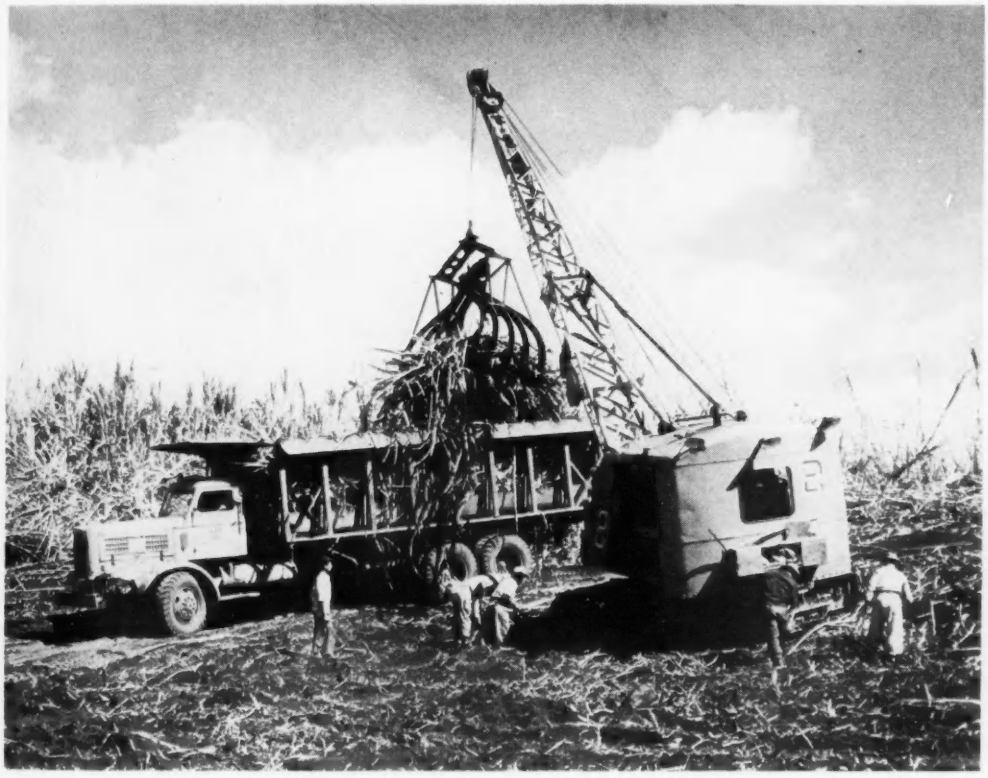

FIG. 17. Harvesting and loading by "grab". (*Photo by R. H. Lodge.*)

(*b*) The expressed juice is clarified by treating with lime or other precipitants.

(*c*) The clarified juice is concentrated by boiling under vacuum until most of the sugar has crystallized.

(*d*) The sugar crystals are separated from the concentrated juice (molasses) by centrifuging.

Each of these four steps involves many details, a consideration of which lies beyond the scope of this article.

practice it is seldom less than six or more than 12.

REFINING RAW SUGAR. Raw sugar contains from two to five percent of molasses and other impurities. At the refinery the raw sugar crystals are washed in a centrifugal to free them of adhering molasses. The washed crystals are redissolved and the resulting sugar solution is further clarified and purged by passing through char and other adsorbents. The

sugar is then recrystallized, separated by centrifuging, dried and packaged as refined sugar.

BY-PRODUCTS. Much remains to be done toward the profitable utilization of the many possible by-products of sugar-cane. The leaves and tops, amounting to three to ten tons of green weight per acre, are equal in value for silage-making purposes to green corn or sorghum. At prevailing wage rates in Hawaii it is not economical to collect the tops by hand, and no mechanical means has yet been devised for salvaging this potentially valuable cattle feed.

As mentioned, the bagasse is used as fuel for generating steam power for the sugar factory. Since bagasse contains 40 percent or more of moisture, its fuel value in terms of coal or fuel oil is low. A small fraction of the total amount of bagasse is presently being used in the manufacture of wallboard, particularly of the insulating and acoustic types. Its use for this purpose will probably increase as the timber resources of the nation diminish.

The "final" molasses which remains after as much as possible of the sucrose has been recovered is used extensively in stock feeds to improve palatability and to increase carbohydrate content. Sugar-cane molasses is also a preferred raw material in the fermentation industries which produce yeast, rum, industrial alcohol, butanol, glycerol and acetone.

In Louisiana the recovery from sugar-cane juice of aconitic acid for use in the plastics industry is a recent development which promises to attain considerable importance.

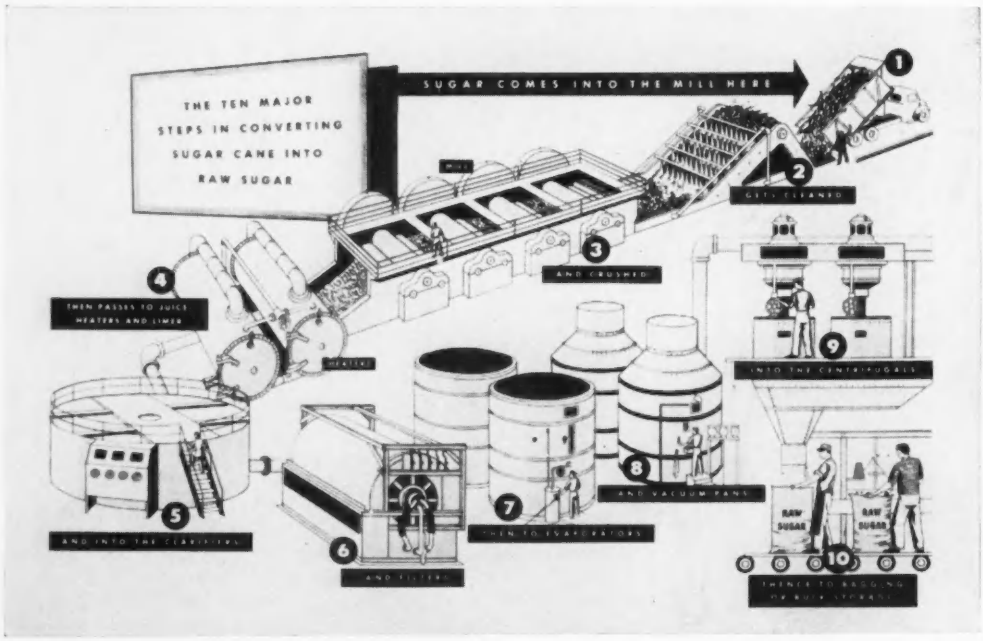

FIG. 18. Flow chart of a cane-sugar factory.

World Production and Consumption

One hundred years ago world production of sugar was estimated at something less than 1,500,000 tons. The estimate for 1948, as shown in Table I, exceeds 37,000,000 tons.

The per capita consumption of sugar in the United States is approximately

100 pounds per annum. In 1938, the most recent year for which reliable world consumption statistics are available, this figure was exceeded by Denmark (122 pounds), Sweden (112 pounds) and the United Kingdom (108 pounds). Asia, with its lower standard of living, has a low per capita consumption of sugar. At the bottom of the list is China with a consumption of only three pounds per person per year.

TABLE I

ESTIMATED WORLD SUGAR PRODUCTION, 1948 *

(In tons of 2000 lbs. raw basis)

	Tons
Principal areas supplying U.S. Market	
U. S. Beet	1,369,000
Louisiana and Florida (cane)	477,000
Hawaii (cane)	835,107
Puerto Rico (cane)	1,275,000
Virgin Islands (cane)	4,000
Philippine Islands (cane)	820,000
Cuba (cane)	5,800,000
Other sugar-producing areas	
Canada (beet)	97,000
Mexico (cane)	818,000
Central America (cane)	154,000
Caribbean Islands (excluding Cuba, Puerto Rico and Virgin Islands) (cane)	1,291,000
Argentina (cane)	623,000
Brazil (cane)	2,026,000
Peru (cane)	540,000
Other South American countries (cane)	468,000
Europe (beet) (excluding USSR)	7,408,000
USSR (beet)	2,000,000
Pakistan (cane)	1,100,000
India (cane)	5,580,000
Formosa (cane)	625,000
Java (cane)	300,000
Other Asiatic countries (excluding Philippines) (chiefly cane)	685,000
Mauritius (cane)	430,000
Reunion (cane)	86,000
Union of South Africa (cane)	608,000
Egypt (cane)	220,000
Other African areas (cane)	304,000
Australia (cane)	1,057,000
Fiji (cane)	150,000
Estimated World Beet Sugar Production	11,081,000
Estimated World Cane Sugar Production	26,069,107
(Total—Beet and Cane)	37,150,107

* From Foreign Crops and Markets, Vol. 58, Number 24, June 13, 1949 (except Hawaii for which actual 1948 production is given).

Bibliography

1. Artschwager, Ernest. Vegetative characters of some wild forms of *Saccharum* and related grasses. U. S. Dept. Agr., Tech. Bull. 951, 69 pp. 1948.
2. Barber, C. A. The classification of indigenous Indian canes. Agr. Jour. India **11**: 371–376. 1916.
3. ———. Indian canes—classification and origin. Trop. Agr. **5**: 320–322. 1928.
4. Brandes, E. W., and Sartoris, G. B. Sugar cane: its origin and improvement. U. S. Dept. Agr., Yearbook 1936: 561–623.
5. ———, and Coons, G. H. Climatic relations of sugar cane and sugar beet. U. S. Dept. Agr., Yearbook 1941: 421–438.
6. Bremer, G. A cytological investigation of some species and species-hybrids of the genus *Saccharum*. Genetica **5**: 97–148, 273–326. 1923.
7. ———. De cytologie van het suikerriet (3de Bijdrage). De chromosomen bij primitieve vormen van het geslacht *Saccharum*. Archief Suikerindus. Nederland. Indie. Mededeel. Proefsta. Java-Suikerindus. Jaargang 1924, No. 16: 477–508. 1924.
8. ———. The cytology of the sugar cane. Genetica **6**: 497–525. 1924.
9. ———. The cytology of the sugar cane. Genetica **7**: 293–322. 1925.
10. ———. De cytologie van het suikerriet (5de Bijdrage) Een onderzoek over de somatische chromosomen aantallen van suikerriet. Archief Suikerindus. Nederland. Indie. Deel III Mededeel. Proefsta. Java-Suikerindus. Jaargang 1931, No. 13: 583–607. 1931.
11. ———. De cytologie van het suikerriet (6de Bijdrage) Een cytologisch onderzoek van een aantal oorspronkelijke Britisch-Indische suikerrietsoorten. Archief Suikerindus. Nederland. Indie. Deel III Mededeel. Proefsta. Java-Suikerindus. Jaargang 1931, No. 31: 1349–1391. 1931.
12. ———. De cytologie van het suikerriet (7de Bijdrage) Een cytologisch onderzoek van een vijftigtal in 1929–1930 op Java geimporteerde rietsoorten. Archief Suikerindus. Nederland. Indie. Deel II Mededeel. Proefsta. Java-Suikerindus. Jaargang 1934, No. 5: 141–166. 1934.

13. Clark, Harold E., and Kerns, Kenneth R. Control of flowering with phytohormones. Science **95:** 536–537. 1942.
14. Clements, Harry F. Factors affecting the germination of sugar cane. Hawaiian Planters' Record **44:** 117–146. 1940.
15. Dutt, N. L., and Subba Rao, K. S. Observations on the cytology of the sugar cane. Indian Jour. Agr. Science **3:** 37–56. 1933.
16. Deventer, W. van. Handboek Suikerriet Cultuur, 5de Deel; Cultuur van het Suikerriet op Java. 472 pp. 1927.
17. Doty, R. E. Ceresan treatment of seed cane. Hawaiian Planters' Record **39:** 333–335. 1935.
18. ———. Rat control on Hawaiian sugar plantations. Hawaiian Planters' Record **49:** 71–239. 1945.
19. Earle, F. S. Sugar cane and its culture. 355 pp. 1928.
20. Grassl, Carl O. *Saccharum robustum* and other wild relatives of "noble" sugar canes. Jour. Arn. Arb. **27:** 234–252. 1946.
21. Hilson, G. R. A note on the inheritance of certain stem characters in Sorghum. Agr. Jour. India **11:** 150–155. 1916.
22. Janaki-Ammal, E. K. Chromosome numbers in sugar cane × bamboo hybrids. Nature **141:** 925. 1938.
23. ———. Intergeneric hybrids of *Saccharum*. Jour. Genet. **41:** 217–253. 1941.
24. Jeswiet, J. Beschrijving der soorten van het suikerriet. Archief Suikerindus. Nederland. Indie. Mededeel. Proefsta. Java-Suikerindus. Jaargang 1925, No. 12: 391–404. 1925.
25. Lennox, C. G. Sugar cane collecting in New Guinea during 1937. Hawaiian Planters' Record **42:** 235–246. 1938.
26. Martin, Joseph P. Sugar cane diseases in Hawaii. 295 pp. Hawaiian Sugar Planters Assoc. 1938.
27. McMartin, A. Chemotherapy in the propagation of sugar cane. So. Afr. Jour. Sci. **42:** 122–130. 1946.
28. Mangelsdorf, A. J. Sugar cane breeding in Hawaii, Part I. Hawaiian Planters' Record **50:** 141–160. 1946.
29. Moriya, Akira. List of the chromosome numbers in the genus *Saccharum* and related genera. Jap. Jour. Genet. **16:** 126–136. 1940.
30. Rumke, C. L. *Saccharum-Erianthus* Bastaarden. Archief Suikerindus. Nederland. Indie. Deel II, Mededeel. Proefsta. Java-Suikerindus, No. 7, 1934.
31. Stephens, J. C., and Quinby, J. R. Bulk emasculation of sorghum flowers. Jour. Am. Soc. Agron. **25:** 233–234. 1933.
32. Swanson, Arthur F., and Parker, John H. Inheritance of smut resistance and juiciness of stalk in sorghum. Jour. Hered. **22:** 51–56. 1931.
33. Takeshita, Takeo. The photoperiodism of sugar cane. Agr. & Hort. (Plant Breeding News) **14:** 33–40. 1939. [In Japanese.]
34. Thomas, R., and Venkatraman, T. S. Sugar cane–sorghum hybrids. Agr. Jour. India **25:** 164. 1930.
35. Van Overbeek, J. Control of flower formation and fruit size in the pineapple. Bot. Gaz. **108:** 64–73. 1946.
36. Venkatraman, T. S. Sugar cane × bamboo hybrids. Ind. Jour. Agr. Sci. **7:** 513–514. 1937.
37. ———, and Thomas, R. Sugar cane breeding technique. Agr. Jour. India **21:** 203–209. 1926.
38. Verret, J. A. *et al.* A method of handling cane tassels for breeding work. Hawaiian Planters' Record **29:** 84–94. 1925.
39. Weller, D. M. Chromosome studies. Hawaiian Sugar Planters' Assoc., Exp. Sta., Ann. Rep. pp. 39–40. 1939.
40. Williams, Francis X. The insects and other invertebrates of Hawaiian sugar cane fields. 400 pp. Hawaiian Sugar Planters Assoc., Exp. Sta. 1931.

Diseases of Fruits and Vegetables Found on the Market, and Means of Controlling Them

Control of market diseases of fruits and vegetables involves not only a knowledge of the fungous diseases affecting these edibles, but also the application of knowledge concerning their physiology through temperature control during transit.

C. O. BRATLEY AND JAMES S. WIANT [1]

Introduction

Market pathology is concerned with diseases that affect fresh fruits and vegetables between the time they are harvested and the time they are consumed. Broadly speaking, it is concerned with the spoilage that occurs during the operations of harvesting, packing, handling, transporting, storing or marketing fresh produce as well as with losses that are encountered by the consumer. It is one of the newer and less emphasized phases of plant pathology, a branch of science in turn that until recently has been concerned more with the problems of the producer than those of the handler and consumer.

During the past 50 years an increasing amount of the produce consumed in the large cities of the eastern United States has been grown in distant specialized areas where climate and soil conditions are favorable for large-scale operations. This trend has been made possible in large degree by the development of facilities for refrigerated transport and of other methods for control of spoilage.

The extent and diversity of produce receipts at a large terminal market are illustrated by referring to the annual reports of unloads at New York City, issued by the U. S. Department of Agriculture. Thus for the year 1947 a total of 190,912 carlots (or carlot equivalents) of fresh produce were unloaded at that market. Ninety percent of these originated in 47 States and the remainder in 21 foreign countries. Twenty-nine different fruits and 89 different vegetables and melons were represented. Of the 172,650 carlots of domestic origin, approximately 43,000 were shipped from California, 31,000 from Florida and 35,000 (chiefly truck shipments) from New York State.

Market produce usually passes through the hands of a considerable number of individuals before it is finally purchased by the consumer. The handling of western-grown lettuce will serve to illustrate the point. The heads are cut and thrown into racks mounted on trailers or placed in field crates which are hauled from the field to the packing house. In the packing house each head is subjected to several separate handlings while being graded, trimmed and packed. The packed crates are lidded and hand-trucked into railroad refrigerator cars, where they are stacked and top-iced. At destination the receiver may inspect the lettuce and divert it to another market

[1] Late Senior Pathologist and Senior Pathologist, respectively, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, United States Department of Agriculture.

or may have the car unloaded and the lettuce trucked to his store. From there it is sold in small lots and delivered by truck to the retailer. It is unpacked, trimmed and displayed by the retailer, and, if not sold promptly, it is retrimmed and rearranged for further display. In view of all this handling, it is not surprising that considerable spoilage is frequently encountered in shipments of this commodity, and of others as well.

Losses from Market Diseases

The economic losses resulting from market diseases have never been adequately determined. Such information as has been developed is largely fragmentary. One comprehensive study, however, shows the losses that are met with in rail shipments at time of unloading.[2] It consists of an analysis of data from over 117,000 inspection certificates issued by Federal fruit and vegetable inspectors at New York City during the years 1935-1942. Highly representative rail carlots of 14 different fruits and 31 different vegetables were covered by the inspections. The average incidence of decay [3] was 2.1 percent for fruit and 3.8 percent for vegetables. Applying these percentages to all rail carlots received during the period, it is estimated that for the 45 commodities under study, decay for all rail shipments to New York City totaled nearly 3,000 carlots annually. True, these figures do not represent total loss, for in some instances the decay either occurred in slight degree, or affected a non-edible portion of the product, or caused a blemished appearance rather than actual spoilage. At the same time they do give some idea of the tremendous importance of market diseases. In computing losses from market diseases, the cost of transporting the commodity to market and, in some instances, the cost of disposing of unsalable produce should be considered in addition to the value of the commodity. However, the results of the study do not indicate where the disease originated, nor where the responsibility lay. Information of a similar nature on losses in boat and truck shipments is conspicuously lacking.

Only a part of the after-harvest losses occur during the transit period. After arrival at the market the produce may be held for from two days to over a week, often at relatively warm room temperature, before it is consumed. Little information is available on losses during the marketing period. Unless packages are reconditioned on arrival at the market, the spoilage that develops in transit is passed on to the distributor. Hence the amount of spoilage reported by the retailer frequently includes all that develops from the time the produce is packed until it is sold to the consumer.

A study by Miller [4] in cooperation with 40 retailers in Knoxville, Tennessee, during the winter of 1934-1935 revealed that losses for these merchants were 20 percent for tomatoes and peppers, 15 percent for tangerines and cabbage, 12 percent for raspberries and onions, 11 percent for cranberries, and 10 percent for cauliflower and strawberries.

An exceptionally detailed study of all types of economic losses occurring in retail produce stores is that of Stokes [5] who reported that losses amounted to 6.9 percent of the retail value of the produce handled. Nearly two-thirds of the loss was actual waste or "garbage loss," of

[2] Wiant, James S., and Bratley, C. O. Spoilage of fresh fruits and vegetables in rail shipments unloaded at New York, 1935–1942. U. S. Dept. Agr., Circ. No. 773, 62 pp. 1948.

[3] A number of leaf spots and troubles of non-parasitic origin are included with decay.

[4] Miller, Paul R. Fruit and vegetable losses in market and kitchen caused by plant disease. U. S. Dept. Agr., Bur. Pl. Ind., Pl. Dis. Rep., Suppl. 88. 25 pp. 1935 (Multigraphed).

[5] Stokes, Donald R. Waste and spoilage losses in merchandising fresh fruits and vegetables in bulk in self-service food stores. U. S. Dept. Agr., Bur. Agr. Econ. Unnumbered Multigraphed Report, 30 pp. 1947.

which undoubtedly much was caused by market diseases.

Loss in the kitchen of the consumer may be the most costly of all losses caused by disease at any stage of the production and transportation of fruits and vegetables. The consumer bears not only the cost of spoilage that develops after the product is purchased, but also that of the spoilage passed on to him by the retailer. In the latter category is the loss from diseases showing little or no external symptoms, and from those, like apple scald, that become apparent in all their severity only after the fruit is held at room temperature.

In his study at Knoxville, Tennessee, Miller [6] obtained the cooperation of 200 housewives who kept records of the spoilage occurring in fruits and vegetables after they were purchased. With few exceptions those showing greatest spoilage were the same as those reported by the retailer: strawberries 15 percent, cranberries and sweetpotatoes 12 percent each, oranges, lettuce and onions 10 percent each, and raspberries and Irish potatoes 8 percent each.

Classification of Market Diseases

Although arising from a number of different causes, market diseases have not generally been classified on an etiological basis. More frequently they have been classified on whether they have their inception before or after harvest and whether development is negligible, slow or rapid during transit. This would seem a useful basis for classification because it indicates when and where control measures probably should be employed and also where the responsibility for loss lies. However, such grouping cannot be followed strictly because many diseases occur both in the field and in transit. Furthermore, the factors that affect the condition at harvest time, though operating in the field, may be of major importance in determining the condition of the produce at the market.

Such a classification to indicate responsibility, if it were possible, would be highly useful to shippers who file thousands of claims with the railroads annually. Many of these claims are paid without contest. On others considerable effort is expended to place the responsibility for the damage. In the past shippers and carriers have considered certain diseases as being strictly transit, and others strictly field. As further information about the diseases has been obtained, these sharp distinctions have somewhat broken down. While certain diseases are characteristically transit troubles, their development is by no means always caused by improper conditions during transit. The produce may be so harvested and handled by the grower as to favor development of decay before the carrier is able to cool it to the proper transit temperature. On the other hand, diseases of field origin may be greatly aggravated by improper transit conditions. In addition, certain diseases, such as gray mold rot of fruits and vegetables and watery soft rot of vegetables, are not satisfactorily controlled by temperatures ordinarily occurring in loaded refrigerator cars.

Parasitic Diseases

Diseases Important Primarily During Transit and Marketing

There are a number of decays caused by fungi and bacteria that, although frequently of field importance, are primarily diseases that affect produce during transit, storage or on the market. Five of the more important are described here in some detail.

BLUE MOLD ROT. This is the name applied to the rots caused by various species of *Penicillium*. The most characteristic symptom is the presence of blue or blue-green spore masses on the

[6] See footnote 4.

decayed areas. *P. expansum* causes the most common and usually the most destructive after-harvest decay of apples and pears. Likewise, *P. digitatum* and *P. italicum* produce the most important market decays of citrus fruits. Other species of this fungus type cause serious losses in cherries, plums, grapes and other small fruits. These fungi are worldwide in distribution and occur on fruits from all producing sections.

The decay starts as a watery, soft, pale brown spot sometimes spoken of as pin-hole rot. In advanced stages the decay remains watery and soft, can be gouged out readily, leaving the surrounding tissue healthy, except in citrus fruits; and it becomes covered with a characteristic blue-green or olive-green sporulation of the mycelial mat. Among the distinctive characteristics of blue mold rot are the musty flavor and odor of the decayed tissue. Although chiefly wound pathogens, these fungi may enter through lenticels in apples and pears or, in the case of *P. italicum*, may penetrate the uninjured skin of the citrus fruit. Conditions that favor the development and spread of blue mold rot in transit and storage are skin breaks in the fruit, moisture and moderately high temperature. New infections rarely occur at temperatures below 50° F., but if already established they will continue their development slowly at temperatures as low as 32° F. Since low transit temperatures greatly retard the development of blue mold rot, the presence of excessive amounts in a well refrigerated shipment usually results from careless handling during picking and packing. Decayed fruits left around a packing house furnish abundant inoculum to infect any skin breaks that may be caused by rough handling.

GRAY MOLD ROT. Decay produced by fungi of the genus *Botrytis* are referred to as gray mold rots because of the characteristic grayish-brown fungus growth that covers the affected parts. Probably most of the species of this fungus affecting both fruits and vegetables after harvest belong to the *B. cinerea* group.

Gray mold rot is the most serious market disease of grapes. It is common on pears, berries, apples, lemons and oranges, and affects practically all vegetables. It is the most destructive of all rots of stored onions.

The decay is firm, semi-watery and without pronounced odor. The most useful diagnostic character is the granular appearing grayish-tan sporulation of the fungus that occurs if conditions are moist. In pears and apples affected areas have bleached, gray, watersoaked borders.

The fungus can penetrate sound epidermis and spread readily from one fruit or vegetable to another in a package and cause a nest of decay. The factor most affecting the development of gray mold rot is moisture. With grapes and onions, particularly, wet weather at harvest is almost certain to be followed by heavy decay in storage. Gray mold is a common decay of produce in cold storage, for it develops and spreads at usual storage temperatures. Responsibility for excessive amounts of decay during transit may rest equally upon shippers, carriers and warehousemen. Control measures must begin at time of packing. Onions should be thoroughly cured, grapes completely dry, and pears packed with chemically treated wraps. The carrier should furnish prompt and effective cooling, and the cold storage warehousemen the proper temperature and humidity conditions. However, if the shipper loaded moist, improperly-cured onions, for example, the loss in transit would be high, regardless of how carefully the proper transit and storage conditions were maintained.

RHIZOPUS ROT. This rot is caused by species of the fungus *Rhizopus*, usually *R. nigricans*. It affects a wide range of

fruits and vegetables and is one of the most important of all transit diseases in shipments that are poorly refrigerated. It is the chief decay of harvested strawberries and sweetpotatoes, and is one of the more important decays of peaches, plums, cherries and Honey Dew melons.

The chief characteristics of the decay are the collapsed, mushy and leaky flesh, and the white or gray strands of coarse stringy mycelium that develop on the affected parts. Because of these characters the decay is sometimes called "soft rot", "leak" or "whiskers". Minute shiny-black spherical sporangia are produced in abundance by the mycelium. In peaches and nectarines the decay is soft and watery, but not mushy as it is in other fruits. This decay of peaches and plums may be distinguished from brown rot by the presence of the coarse mycelium, by the black sporangia and by the ease with which the skin may be slipped from the center of the affected areas.

Rhizopus, the causal fungus, has an exceedingly wide distribution, and its spores are generally abundant in the field, packing house, freight car and market. Skin breaks are essential for penetration of the fungus. Fresh, turgid, moist tissues are more susceptible to invasion than are wilted ones. Rhizopus rot is considered a high-temperature decay. Various species of *Rhizopus* differ in their temperature relations but, in general, temperatures below 50° F. prevent active growth. When a shipment is found severely affected with Rhizopus rot on arrival at the market, insufficient refrigeration may usually be blamed.

WATERY SOFT ROT. This rot is also called "pink rot", "cottony rot" and "Sclerotinia rot". It is the most important after-harvest disease of celery and some of the other leafy vegetables. It affects all of the principal vegetables with the possible exception of potatoes and onions. It may occur in the field as a damping-off of seedlings, as a basal rot of the stems and leaves of older plants, or as a decay of the upper part of these plants.

Affected areas become watersoaked and soft and turn light brown to pink. The decay has no characteristic odor. The presence of the white fluffy causal fungus (*Sclerotinia sclerotiorum*) affords the most important diagnostic characteristic. In advanced stages the fungus produces numerous large irregularly shaped sclerotia or resting bodies scattered in the mycelium or in the tissues of the affected vegetables. At first these are white but later turn black.

The sclerotia persist in the soil of the field until suitable moisture and temperature allow them to germinate, sending mycelia through the soil or developing fruiting bodies from which spores are forcibly discharged. Infection of the plant by either spores or mycelium depends chiefly on the presence of moisture. Wounds are not necessary for penetration, but the presence of areas killed by other agencies, such as freezing, render the vegetable especially susceptible. Even though no decay is visible at time of packing, if the vegetable was harvested from a field showing important amounts of decay, some may be expected to appear later. Small infections may develop and spread extensively during a short transit period unless temperatures are low. Optimum temperature for development is about 75° F., but lesions will enlarge at temperatures as low as 32° F. Because of the tolerance of low temperature by the fungus, severe losses may occur in vegetables held in storage at 32° F.

BACTERIAL SOFT ROT. This is the most important of all decays affecting vegetables after harvest. Practically all kinds may be affected, but potatoes, carrots, celery, cabbage, lettuce and tomatoes are particularly susceptible.

The typical decay is soft, mushy and

sticky, and early develops a very offensive odor due to the activity of secondary organisms. At first it has a greasy appearance and a definite border. If warm moist conditions prevail, extensive leaky collapse of the tissues occurs. Under dry cool conditions the decay may become arrested and the affected tissues dry down to a brittle or a chalky consistency.

The decay is caused by *Erwinia carotovora* and possibly closely related species of bacteria. These organisms live in the soil on plant debris and enter the plant through wounds caused by insects, cultivating and harvesting tools, or through lesions of other diseases. Certain diseases, such as the late blight tuber rot of potatoes, are commonly followed by bacterial soft rot. The decay is severe only under warm moist conditions. If the harvested product is cooled to 45° F., very little decay develops. In recent years a number of shippers of potatoes have installed hot-air driers to remove the surface water from the washed potatoes in order to make them less susceptible to bacterial soft rot.

DISEASES IMPORTANT BOTH IN THE FIELD AND ON THE MARKET

Many fungus diseases that are well recognized as being field troubles continue to cause losses after harvest. Brown rot of stone fruits and common scab of apples may be offered as examples.

BROWN ROT. This disease is caused by the fungus *Sclerotinia fructicola*. It causes more loss to the peach and plum growers than any other one disease. It may blight the blossoms, thus preventing set of fruit, and it may affect leaves, twigs and limbs as well as fruit on the tree. At terminal markets brown rot is the chief cause of loss in all stone fruits. Fruits that appear sound when picked and packed may show high percentages of rot after a three-day transit period. This disease causes a brown, watery, firm decay that involves large areas on the fruit. The skin on the affected area is not sunken, remains firmly attached to the flesh and turns dark brown to black in late stages. Very little surface growth of mycelium is present, but yellowish-gray powdery masses of spores are formed.

Much of the brown rot that develops results from infections in the orchard. Infection takes place through skin breaks caused by insects, winds and other agencies, and usually occurs during rainy periods just previous to harvest. If the car is poorly refrigerated, infection progresses rapidly and may spread by contact to sound fruit. Prompt and thorough refrigeration will retard development of the decay but will not prevent it, since some enlargement can occur at 32° F. Responsibility for losses from this disease is generally placed on the grower.

APPLE SCAB. This is the most costly of all orchard diseases in the East because frequent and thorough spraying must be done to protect foliage and fruit from it. The causal fungus, *Venturia inaequalis*, causes a shallow, black, corky spot. Scab lesions present on the fruit at harvest detract from the appearance, allow more rapid loss of moisture than through intact skin, and may open the way for decay-producing organisms. Old spots enlarge but little on apples in cold storage. An unusual amount of scab developed in storage in 1939 on eastern fruit picked after a wet period of nine or ten days preceding the hurricane of September, 1938. Apples that were apparently free from scab when harvested were badly spotted after four months in cold storage. It had previously been shown that lesions appearing in storage are the result of inoculations occurring while the fruit is on the tree. Unusually long wet periods were found necessary for infection of the fruit as it matures. The cold storage warehouse manager should not

be held responsible for scab on stored fruit because slight variations in the temperature or humidity of the storage room have no effect on enlargement of scab lesions resulting from late orchard infection. "Storage scab" must be controlled by the application of fungicides late in the growing season.

VIRUS DISEASES[7]. Diseases induced by viruses have been of increasing importance in the field, where they produce distortion, abnormal coloration and lack of fruitfulness in a wide variety of plants. Fruits or vegetables deformed or mottled by viruses are usually discarded during grading and thus seldom reach the market, at least in great amount. Occasionally, however, virus-affected produce, such as lettuce heads spotted and blemished by spotted wilt and celery deformed and discolored by mosaic, are found on the market. Some virus diseases of tomatoes may escape detection at the shipping point and cause considerable market loss because of their adverse effect on color development in ripening. On arrival at the market tomatoes are usually sorted, and the green fruits are held in ripening rooms to color. As the affected fruits ripen, circular yellow or light brown areas appear, or the ground color remains yellow with spots of red scattered over the surface. Such affected fruits cannot be detected at picking time but must be sorted out and discarded or sold at a reduced price after ripening on the market. All control measures must be applied in the field, for variations in transit and handling methods apparently have little effect on the severity of the mottling, and there is no spread of infection in the harvested produce.

Non-Parasitic Diseases

There are several non-parasitic market diseases of fruits and vegetables. Some of them have their inception in the field; others result from conditions operative after harvest. The following are some of them.

BLOSSOM-END ROT OF TOMATOES. This is a disease of field origin that produces shallow dead areas at or near the blossom end of the tomato. At first these lesions are water-soaked and dark green. Later they collapse and become leathery and dark brown. Frequently organisms enter through the spot and produce typical decay. Certain growing conditions, particularly disturbed water relations, are thought to favor development of blossom-end rot. Since the disease may not appear for several days following the environmental disturbance that brings it on, tomatoes that are apparently healthy when packed may develop blossom-end rot in transit and on the market. Here, again, the transportation company and receiver should not be held responsible for the losses involved.

BITTER PIT OF APPLES. This is a market disease of field origin which seems to be little affected by handling practices. It is characterized by small sunken spots scattered over the surface which result from the collapse of patches of cells beneath the epidermis. These spots are more deeply colored than normal skin and resemble tiny bruises. Sometimes tissues deep in the flesh are affected. When the apple is sectioned it may be seen that the patches of dried cells are scattered throughout the flesh and are usually connected with the water-conducting system of the fruit. There are some indications that the killing of the patches of cells in the flesh is due to desiccation, the moisture from them being withdrawn by neighboring cells having greater osmotic pull. Apparently this condition occurs when moisture is withdrawn from the fruit by the leaves under conditions of drought or rapid growth.

Fruits that are apparently sound when picked may develop bitter pit during

[7] Included here with parasitic diseases because of their infectious nature.

transit and storage, and spots already present may enlarge. Frequently 50 percent of the Gravenstein apples in shipments said to have been free from bitter pit when packed in California are found affected on arrival at the New York market. Other varieties that are especially susceptible are Baldwin, Northern Spy and Rhode Island Greening. In fact, the disease is so common on the first named variety that the disease is often called "Baldwin spot". Apparently little can be done to control bitter pit after the fruit has been picked, but it has been reported that some delay in its appearance can be expected if the fruit is waxed before it is stored or if it is stored under high relative humidity.

APPLE SCALD. This is an example of a non-parasitic market disease that is caused by products emanating from the fruit itself. Although certain growing conditions render the fruit more or less susceptible to the disease, control measures may be initiated at harvest time or thereafter.

Scald affects the skin of the apple and is confined largely to the greener side. It appears as a diffuse browning as though a poorly defined area had been killed by heat. Extensive studies have shown that during storage at low temperature the apple gives off certain odorous gases called esters that apparently accumulate in the skin of the fruit and kill the epidermal cells. Thorough ventilation of exposed fruits in a pack greatly delays the appearance of scald but causes the apple to lose undue amounts of moisture. Mineral oil applied to paper fruit wrappers or to shredded paper that is mixed with the fruit absorbs these esters and affords commercial control of the disease. Apples from the West are now usually packed in tissue wraps containing oil. Many eastern-grown apples are packed with shredded oiled paper.

This disease had been the cause of considerable controversy in the past between shippers and receivers because it rarely develops on apples until they are removed from storage and held in a warm place. Thus fruit that was apparently free from scald in the storage room would become severely scalded after being placed on retail stands or held in the consumer's home. The receiver and retailer can do little to prevent its appearance, for the injury has already occurred and warmth merely hastens oxidation in the dead cells. Less browning would occur if the fruit could be kept cool until consumed.

ABNORMAL RIPENING OF PEARS. A physiological disorder of pears, controllable only after harvest, is of particular interest both to retail dealers and to the consumer. For a number of years complaints were made by retailers that early-season Bartlett pears from the Sacramento River Valley of California failed to ripen properly but instead remained granular and flavorless or became broken down. Studies have indicated that this early-season fruit was not by nature lacking in dessert quality, nor was lack of thorough transit refrigeration responsible for improper ripening as had been supposed by some. The poor quality and break-down was found only in fruits ripened at temperatures above 80° F. Pears that were ripened at 65° to 70° were free from breakdown and were of excellent dessert quality. Those ripened at 75° were but slightly inferior to those ripened at 70°.

A consideration of the conditions under which these early-season Bartlett pears arrived at the market in July and August shows that they are ordinarily ripened at room temperatures that average several degrees above 80° F. Such temperatures prevent normal ripening and are responsible for the breakdown.

INJURIES

BRUISING. Broadly speaking, market pathology includes the study of spoilage in fruits and vegetables due to physical injuries. Of these, bruising plays an im-

portant role, both directly in destroying the structure of the product and indirectly in furnishing points of entry for decay-producing organisms. As has already been pointed out, extensive blue mold rot in shipments of California oranges follows skin breaks due to careless handling. When careful handling is practiced, the amount of spoilage drops greatly.

Bruising of apples in the bottom-layer boxes in rail shipments is commonly encountered and causes considerable loss each year. Usually only the apples along the side of the box next to the floor of the car are affected. The bruising and flattening of the fruit formerly was confused with freezing injury because of the glassy water-soaked appearance of the affected tissue, and because frozen tissue is well known to bruise easily. Many claims for damage were paid by railroads before it was shown that this typical transit injury could be produced at non-freezing temperatures by jolting apples in commercially packed boxes to simulate transit conditions.

HEATING. Sun-burning and the more severe sun-scalding are often found on market offerings of apples, tomatoes, grapes, peppers and Irish potatoes. The areas are bronzed or killed by the heat of the sun and may become invaded by rot-producing organisms. On apples the effect of slight sunburn may not be visible until the fruit has been held in storage for a number of months. This "delayed sunburn" is common on Yellow Newtown apples sold on the market in the early spring months.

Injuries by high temperatures may be produced on fruits during the washing process in the packing house. Apples and oranges, for example, are frequently washed in heated solutions during packing house operations. Injury occurs either when temperatures exceed the prescribed limits or when fruit is exposed too long. The injury may not appear for several hours or days after treatment. Thus fruits that are apparently sound when packed may be found badly affected on arrival at the market. In apples the injury may appear as minute checks or cracks, or as large, rubbery, brown patches in the skin. Similarly in oranges small patches of cells in the skin may be killed and become pitted or large areas may take on a cooked appearance. Frequently a small, well-defined, circular area on the fruit may remain normal. This is the part that was not submerged as the fruit passed through the hot bath.

FREEZING. It is not uncommon during the coldest months of the winter for the layer of apples or pears next to the floor of a refrigerator car from the Northwest to be frozen solid upon arrival at the eastern market. Fruits and vegetables sometimes are also frozen in storage by accidental lowering of temperatures.

While still frozen, apples and pears are hard, show fine reticulations in the skin, and contain in the flesh ice crystals that can be detected readily by tasting. Frozen fruits contract slightly while being frozen, making the pack less tight and the fruit more subject to bruising.

The freezing temperature of most fruits and vegetables lies between 28° and 30° F., but some commodities, such as lettuce, freeze at temperatures very close to 32°, the freezing point of water. It is believed that freezing injury is caused chiefly by dehydration of the cells and by the physical effect of ice crystal formation in the space between the cells. Certain fruits and vegetables may recover from slight freezing without apparent injury. However, they usually deteriorate rapidly and are more susceptible to fungus decays. Products that are severely frozen become water-soaked and flabby on thawing. Celery and other leafy vegetables often show a characteristic blistering and loosening of the epidermis.

Some fruits may be injured by short exposures to temperatures well above the freezing point of their tissues. Green

bananas thus are injured by exposure to temperatures below about 56° F. Avocados, pineapples and limes are likewise subject to "chilling injury" when stored for several days slightly below 40° F. The browning of the skin or flesh in these fruits is apparently not due to physical injury but to killing of the cells through abnormal physiological activity.

CHEMICALS. Various chemicals applied for some utilitarian purpose or accidentally brought in contact with fruits and vegetables may cause damage. Probably the most common chemical injury seen on the market is that on apples caused by hydrochloric acid or sodium silicate solutions used for spray residue removal. Such injury follows the use of too concentrated solutions or the failure to rinse the fruit thoroughly after washing. Killed areas in the skin, light tan if caused by the acid, brown if caused by sodium silicate, are produced most frequently in the calyx and stem cavities where rinsing is difficult. Another chemical injury that often accompanies injuries from washing solutions, but which may be present on apples that have not been washed, is arsenic burn. Caused by the accumulation of water containing soluble arsenic from spray residues in the calyx cavity, this injury may occur during rainy periods while the fruit is in picking crates in the orchard, or may follow failure to rinse away drops of old washing solutions in which soluble arsenic has accumulated. This injury often does not appear until three or four weeks after application of the chemical.

Another kind of chemical injury which appears occasionally on the market is the formation of dark, flattened, rubbery areas on potatoes and watermelons shipped in bulk. The injury occurs on fruit or vegetables in contact with the sides and walls of box cars previously used for shipping salted hides or caustic chemicals. A similar injury caused by caustic substances from the package materials is sometimes found in apples packed in boxes made of Douglas fir and in onions packed in bags containing an alkaline sizing material.

Ammonia, escaping through leaks in refrigerating coils, sometimes injures large holdings of fruits and vegetables in cold storage plants. Affected apples become brown-spotted at the lenticels, and the outer scales of onions turn a deep brown color.

As will be pointed out later, certain gases are used to fumigate fruit for decay control. Sulphur dioxide, commonly used on grapes at packing time and during storage, frequently causes some injury to the fruit. In mild cases only a small circular area on the berry at the loosened cap stem attachment is affected. In severe cases large areas are bleached and the fruit becomes dull and astringent.

Control of Market Diseases

Successful control of market diseases must begin in the field. Products from thrifty plants on which diseases and insects have been thoroughly controlled will generally reach the consumer in much better condition than products from plants that are unthrifty or diseased. Since many of the important transit and market diseases discussed previously have their inception before harvest, control of disease in the field is doubly important in safeguarding the product. Weather conditions during and just previous to harvesting have been shown to be important in determining later market condition. Thus the appearance of leather rot caused by *Phytophthora cactorum* in shipments of strawberries has been found closely correlated with rainfall before picking. The rot was found to reach a maximum within three or four days after heavy rains. Storage scab of apples has been reported unusually severe on fruit picked after an extensive rainy period that occurred immediately before harvest.

Care in harvesting is essential to prevent physical injury to the product. Many fungi causing decay require skin breaks in order to penetrate the fruit or vegetable. Thus it has been found that care in picking and packing to avoid skin breaks has resulted in a marked reduction of decay in shipments of strawberries and of oranges. Thorough culling out of diseased individuals is essential before fresh produce is packed. Frequently one or two diseased individuals in an otherwise disease-free pack will become centers of infection around which nests of rot develop during transit and storage. Decays caused by *Botrytis* on berries, grapes and pears, and by *Rhizopus* and *Sclerotinia* on green vegetables, commonly spread in this manner.

Pre-Shipping Treatments

Increasing attention is being given to supplementary treatments for decay prevention that may be carried out after the product is harvested and before it is shipped to market. Most of these are of a chemical nature in which a fungicide in the form of a wash, a dust or a gas is applied. Some of the chemicals are effective instantaneously and for short periods only, whereas others become effective slowly by indirect methods and last for extended periods. These measures attempt to eradicate the microorganisms or to protect the produce from infection, and are effective only before the pathogen has penetrated the tissue deeply.

Solutions of borax have long been used for the control of citrus decays. Borax treaments have likewise shown some promise for control of cantaloup decays and for the control of Phoma rot of tomatoes.

Hypochlorites, as well as free chlorine, have been reported as reducing bacterial and fungus rots when applied to the water used for precooling and washing various fruits and vegetables.

Many other chemicals have been tested in solution form for the control of citrus rots and for the control of decays of other commodities. Excellent decay control has been obtained with some of them. Thorough tests are necessary, however, to determine whether there are any deleterious effects from a new treatment before it can be adopted for commercial use.

Painting the freshly-cut stems of watermelons with copper sulphate paste has proved successful as a control measure for stem-end rot caused by the fungus *Diplodia*. Similarly black rot of pineapples, caused by *Ceratostomella paradoxa*, has been greatly reduced in amount by treating the cut stems with a tincture of benzoic acid. Fungicides in dust form have been applied to harvested products to prevent transit decay. Probably the treatment having greatest commercial use is that of sulphur dust for brown rot control on freshly harvested peaches. In order to obtain a more attractive product, peaches are often brushed to remove the fuzz. This tends to increase brown rot infection. It has been shown that under certain conditions, sulphur dust applied to the fruit is effective in reducing new infections of brown rot in transit.

The most commonly used fungicide in gas form is sulfur dioxide which has been applied for many years to harvested grapes in California. The sulfur dioxide is now generally applied from cylinders of compressed gas through special mixers. The grapes are treated first either in the storage room or refrigerator car immediately after picking. Care must be used in applying the gas, not only because of its toxicity to humans but because under certain conditions it may cause severe injury to the fruit. The injury occurs first at the cap-stem attachment or at skin breaks on the grape and appears as a bleaching of the tissue. Since the injury does not appear in all of

its severity until after the grapes have been warmed to room temperature for at least a day, much of it is first noted after the fruit is on the market.

Another gas now in commercial use as a fungicide on freshly harvested produce is nitrogen trichloride. It has been used chiefly for the control of blue mold rot and green mold rot of oranges, and it has proved effective in reducing decays of cantaloup. It has been employed extensively on tomatoes. Commercially the gas is prepared as it is used and is applied by circulating it through the refrigerator cars or, in the case of oranges, in holding rooms as well.

A number of other chemicals in gas form are occasionally used on fruits and vegetables. Among them are ozone, ethylene oxide and methyl bromide. The latter two are used as fumigants for insects and in most cases reported have had little or no beneficial effect on the control of decay. Employment of ozone as a fungicide in fruit storages has been tried by a number of investigators with varying results. It appears that the gas may be expected to inhibit the growth of surface molds and to reduce odors but cannot be relied upon for control of decays in stored products.

Fungicidal gases may be applied in transit or storage by packing with the fruits and vegetables a material that gives off the gas slowly. One such material is sodium bisulfite which, in powder form, is mixed with the sawdust filler in certain types of grape lugs or is sifted into the cushion upon which the grapes are packed. When exposed to moisture in the air this chemical slowly releases sulfur dioxide which is effective for the control of gray mold rot.

Impregnating paper wraps with volatile materials has been attempted with a number of fungicides for the control of decay in citrus and other fruits. Several have given promising results. Thus diphenyl wraps give considerable control of both blue mold rot and stem-end rot of citrus. Similar results have been obtained with diphenyl-impregnated cardboard or paper box liners that completely enclose the fruit in the packed boxes.

The control of two important diseases of fruit in storage is effected by means of non-volatile materials impregnated in paper wraps. Thus apple scald can be controlled or greatly reduced by packing the fruit with wraps or shredded paper containing mineral oil. Apparently scald is caused by the accumulation of esters or similar products of the apple in the tissues of the fruit and in the surrounding air. These toxic substances are absorbed by the mineral oil in the paper. The other storage disease commercially controlled by a non-volatile substance impregnated into the wraps is gray mold rot (Botrytis rot) of pears, which in the case of plain wraps is capable of spreading from fruit to fruit in the box. When the wraps are impregnated with certain copper compounds the fungus is unable to grow beyond the barrier, and the decay is thus restricted to the fruits already affected before packing.

Temperature Control Measures

Decreasing the temperature of fresh produce reduces its rate of respiration and thus prolongs its market life. Thus a reduction of 18° F. slows down ripening of the fruit or vegetable by approximately half. The optimum temperature for growth of most of the decay-producing organisms lies between 70° and 80° F. The rate of their activity decreases progressively with lowering of temperature. Some fungi become inactive or only slowly active at 45°–50°. Others continue to develop even at 32° F. Theoretically it would seem advantageous to store produce at as low a temperature as

possible without freezing it, yet many fruits and vegetables apparently develop abnormal physiological activities at such low temperatures. Potatoes subjected to temperatures below 38°–40° become undesirably sweet. Actual visible injury may occur on some fruits held at a chilling temperature. Thus the peel of bananas turns a leaden gray when held at temperatures below 50° F. Such serious physiological diseases as pitting and blotching occur on lemons if stored below 50° F. Inasmuch as many fruits and vegetables have unusual temperature relations, it is necessary to ascertain the optimum storage condition for each commodity.

TRANSIT REFRIGERATION. Refrigerator cars are used for rail shipments of most produce. They are well insulated and have a basket-type bunker in each end to hold the ice. Circulation of the air in the car is by gravity, air being cooled by the ice and passing downward and out into the lower part of the lading space. As this cool air removes heat from the produce and consequently is warmed up, it rises to the top of the car and circulates back into the top of the ice bunker where it is again cooled. Many cars are now being equipped with fans located at the bottom of the ice bunkers and powered by a friction drive on the wheels of the car. When the car is in motion the fans operate and force the air up through the ice and out over the top of the load. This tends to equalize temperatures in top and bottom layers of the load.

Some specially designed refrigerator cars have top bunkers rather than conventional end bunkers. These consist of flat ice tanks, suspended from the ceiling, which are charged through hatches in the roof of the car. Below the tanks are baffles connected to ducts that direct the flow of cold air down along the sidewalls of the car and out under the load. Because the circuit around which the air travels is much shorter than it is in the end-bunker car, the produce is cooled more quickly and with less difference in temperature between top and bottom of the load.

To hasten the cooling of produce in a refrigerator car, salt is frequently added to the ice.

The common practice used in shipments of lettuce and many other vegetable commodities is to add ice directly to the shipping container at the time of packing and to the load by the application of top ice over the entire contents of the car. Usually snow ice is blown into all crevices of the load as well as on top of the packages. No ice is added to the bunkers, but the top ice is replenished at intervals during transit.

PRECOOLING. It usually takes three to five days to cool the top-layer fruit in an ordinary refrigerator car to a temperature of 50° F. This allows time for decay-producing organisms to become well established and for the fruit to ripen materially. Because of this, shippers frequently harvest their produce in an immature stage that is less subject to ripe rots and to loss from over-ripeness. However, fruit so harvested usually never attains the good eating quality of plant-matured fruit.

To avoid these troubles the practice of precooling has become well established in many shipping districts. Precooling has been defined as "the comparatively rapid reduction of the temperature of a commodity before shipment to or below that temperature which it might ultimately attain during transit under conventional refrigeration practice"[8].

Produce may be precooled either before it is stowed in the car or afterward while the car is held on the siding. In highly specialized producing areas packing is often done at central plants

[8] Fisher, D. F. A review of precooling practice. Refrigerating Engineering, April, 1938.

equipped with refrigerated rooms for precooling or for over-night storage. Immediately after the produce is packed it is stacked in the precooling room in such a way as to allow free circulation of air around the packages. Forced circulation of the air is usually provided.

A number of leafy and succulent vegetables, such as celery and asparagus, are regularly precooled by immersion in ice water. In practice the crates of packed vegetables are conveyed partly submerged through a long tank of cold water while being sprayed from above with water chilled to 32° or 35° by cooling coils or crushed ice. Usually 20 minutes or less are required for precooling. Afterward the crates are placed without delay in iced refrigerator cars.

By far the most common practice is to precool the produce after it has been loaded. One method for accomplishing this is to connect the cars by air ducts with refrigerated bunkers and to force cold air from the latter through the loads. Air at 23° to 25° is used, and from six to eight hours of continuous blowing is required to reduce the temperature of a carload of produce from 80° to 45° F.

At shipping points where refrigeration plants are not available, precooling is obtained either with mobile refrigerating units or by salting the ice in the bunkers and operating fans inside the car to hasten circulation of the air. Mobile precooling units are mounted on and receive their power from gasoline-operated trucks. The truck with compressor and cooling coils is driven up to the open door of the car to be precooled. A canvas duct connects the truck with the door of the car, and cold air is blown in at the top of the door and withdrawn at the bottom. A canvas baffle is placed over the top of the load near the door to prevent short circuiting of the air.

The method of circulating the air by fans over the ice inside the car is the one most commonly used. Usually an amount of salt equal to five percent of the weight of ice is thoroughly mixed with it in the bunkers. Electrically operated fans of the propeller type are placed inside the lading space of the car, usually at the top bunker openings. The remainder of the bunker opening is covered to prevent by-passing of the air. The fans are tilted slightly to direct the air from the bunker diagonally down on the top of the load. It is necessary to replenish the bunkers with ice and salt at the end of each three- or four-hour period. The salt dissolves and drains away rather rapidly, but it is important not to add salt during the last hour or so of precooling to avoid danger of freezing the produce at the bottom bunker position after precooling is finished and the car is in transit.

Another method of car precooling is to make a single application of snow ice over the top of the load soon after the completion of loading. This has been particularly successful with cantaloups. The practice is to add enough ice so that by the time it is melted the cantaloups will have attained a transit temperature that can thereafter be readily maintained by refrigeration from the bunker ice. The method has been tried on a number of different commodities that appear not to be injured in any way by the water from the melting ice.

These methods of car precooling have the advantage not only of rapid cooling of the load, but also of cooling the top layers more rapidly than the bottom layers. As pointed out previously, in cars not permanently equipped with fans the top layers are the slowest to cool while the car is in transit.

Use of Modified Atmospheres

It has long been known that if fruits and vegetables are held in atmospheres deficient in oxygen or rich in carbon dioxide their respiration rate is reduced. A number of investigations have been

carried out to make use of this principle in prolonging the storage life of fruit. Thus British workers have found they could double the storage life of certain varieties of apples by holding them in an atmosphere containing 14 percent of carbon dioxide and 8 percent of oxygen. As a result of such studies a considerable number of commercial controlled-atmosphere storages have been put into operation in England. Investigations in this country have led to the construction of a few such storages, used chiefly for McIntosh apples which, like the English varieties, are subject to low-temperature disorders when held at the usual apple storage temperatures of 31°-32° F. By the use of gas-tight storage rooms oxygen becomes somewhat depleted, carbon dioxide is built up, and the fruit can be held at somewhat higher temperatures, thus avoiding low-temperature injury.

Considerable experimental work has been done in this country on the use of carbon dioxide as a supplement to ice refrigeration in transportation of fruits. In some instances results have been so good that it seems likely that increasing commercial application will result. The method of application is to place a quantity of dry ice within the car. It has been found that these initial carbon dioxide treatments at temperatures commonly prevailing in freshly loaded cars of stone fruits usually have as favorable an effect in retarding decay and in holding the firmness of the fruit as does immediate storage at 32° F. Such treatments checked ripening and decay until the fruit could be cooled by the usual transit refrigeration, thus having the same effect as rapid precooling. Carbon dioxide has been used extensively in commercial shipments of cherries from California and the Pacific Northwest to eastern markets.

Strawberries and other berries have been found to benefit from initial carbon dioxide treatments, but may be injured in flavor by subjecting them to the gas over too long a period. Concentrations of carbon dioxide of 25 percent for the first 12 hours with a gradual reduction in concentration thereafter are safe and effective in reducing decay and retarding ripening. Such reduction takes place naturally by leakage of the gas from the car.

The use of carbon dioxide in the transportation of pears has been investigated by a number of workers. Pears are tolerant of gas storage and would benefit by transportation in rather high concentrations of carbon dioxide. One of the chief hindrances to general use of the gas is the rapidity with which it escapes from the usual refrigerator car, thus making it impossible to maintain high concentrations over long periods.

It has been found that pre-storage treatment with carbon dioxide retarded softening of apples and materially protected the Jonathan variety from soft scald and soggy breakdown, two diseases that are often serious when this variety of apple is stored directly at 32° F.

Papain—*The Valuable Latex of a Delicious Tropical Fruit*[1]

This latex of the well known tropical papaya fruit contains protein-digesting enzymes and so finds utilization in digestive medicines and in tenderizing meats. It is valued also in the brewing and tanning industries and in the manufacture of chewing gum.

THOMAS LEWIS AND E. F. WOODWARD
S. B. Penick & Co.

Papain is the dried and purified latex obtained from the green fruit of papaya (*Carica Papaya*), a tree native to Latin America but now cultivated throughout the tropics of the world because of its commercially valuable edible fruit. Shortly before the turn of the century scientific note was taken of the native custom of tenderizing meats by wrapping them in papaya leaves prior to cooking. These observations led to the discovery that the active substances accounting for the tenderizing effects of the leaves exist to a greater degree in the latex of unripe fruits. In 1878 Henri Wittmark of Berlin made a careful examination of the properties of the dried latex.

It was noted that the freshly collected latex coagulates and dries rapidly, all the while retaining its activity. It therefore had commercial possibilities and was introduced into commerce. Ceylon was the main source at first, and papain is still produced there in small lots by many individual farmers. At intervals the export merchants send buyers around the countryside to bargain for these small lots. The papain is then graded and bulked. The finished product varies in color from a light creamy white, through dark yellow and orange tints to an almost chocolate brown. And, if the semi-dry latex is forced through a sieve prior to the final drying, the product instead of being irregularly granular is in more uniformly sprill-like pieces.

The country producing the most and best grades of papain today is Tanganyika, a British Protectorate in East Africa. Production was commenced there in 1937 near the cities of Arusha and Moshi. Snow-capped Mount Kilamanjaro is the center of the growing region where the trees thrive at elevations between 4,000 and 4,600 feet. Another producing area is to the north, in the British colony of Kenya, but Tanganyika leads in production. The port of shipment from both areas is the humid city of Mombasa on the coast of Kenya.

African papain is produced on large estates, some of which also yield pyrethrum flowers, corn, beans, sisal, coffee and other agricultural products. The owners and managers of these estates are from the Continent and the British Isles, but the workers are natives. The trees are set out in rows, growing 20 to 40 feet tall, and bear clusters of their large melon-like fruits at the base of their long-stemmed leaves at the upper end of the trunk.

Since these fruits are 15 or more feet from the ground and are not removed from the trees in order to obtain their latex, an army of trained workers, carrying poles tipped with a sharp metal finger, a razor blade or a splinter of

[1] This article is an adaptation, in most parts verbatim, of an article in Drug and Cosmetic Industry 63: 734. 1948, supplemented with information from the U. S. Dispensatory.

bamboo, taps them for the latex. The fruits must be incised at a precise time in their period of growth, and only the outer skin must be scratched. Tapping is performed in the early morning, every four or five days, and to catch the dripping latex, a sort of clamp-on inverted umbrella is placed around each tree. When a few pounds of latex have fallen, other native workers collect the semi-coagulated material and carry it to modern brick drying kilns.

The dried latex is carefully graded and sorted, and much of it is tested in government laboratories before shipment. The finished product is more uniform in color than is the Ceylon type, although the color may range from light cream to medium orange. Contrary to the general conception, the color of different parcels of Tanganyika papain has little to do with the relative activity, and nearly all Tanganyika papain is more active than the type from Ceylon. Purification is effected by dissolving the crude substance in water, precipitating with alcohol, and drying the precipitate.

Each tree yields from three to eight ounces of dried latex per year. An acre of trees furnishes from 80 to 175 pounds per year, and around five pounds of fresh latex are needed to make one pound of dried latex, or papain. Maximum latex yield occurs at the end of 12 to 14 months, and a tree is old at the end of six years.

At various times papain has been produced in most of the tropical countries of the world, including India, Samoa, Philippines, Belgian Congo, Haiti, Cuba, Mexico, Brazil, Uganda, Siam, Netherlands East Indies, Hawaii, Tahiti and Jamaica. Ceylon and Tanganyika are the important producers, and the imports of papain into the United States were 54,344 lbs. in 1925, 111,209 lbs. in 1934, 273,159 lbs. in 1939, and 315,021 lbs. in 1945.

Papain, especially from Ceylon, has always been subjected to clever sophistication. Starches, coconut, gum arabic and cashew resin have all been used for such adulteration, but various methods for detection have been devised. Its activity is affected by various factors: age of the trees from which it is collected; ripeness of the fruit; time of day of tapping; season of collection; speed of drying; condition of the soil; amount of rainfall; temperature at which the latex is dried; care and promptness of packing; and method of storage. The material seems to lose considerable activity within the first two or three weeks after preparation, regardless of the care in handling.

Utilization of papain is principally as a protein digestant and is dependent upon its content of enzymes, of which there are five or more in the latex. The most predominant of them is proteolytic in action, the second clots milk and others have some action on fats and starches. Papain is active over a relatively wide range of temperatures, freezing does not have any deleterious effect on it, and activity increases with temperature, even withstanding the heat of pasteurization, about 80° C. The predominant enzymes are said to be most efficient when in an acid medium, but they have some activity in alkaline and neutral surroundings. These facts must be taken into consideration in using papain in digestive preparations, and, since the larger phases of protein digestion occur in the intestines, use of an enteric coated dosage has been suggested. But since papain is active in both acid and alkaline media, it can be used to assist both gastric and duodenal digestion.

Its use as a digestant is only one of many uses. In a manner similar to the uses of maggot extracts (allantoin), papain has been employed in the treatment of ulcerous skin conditions. Natives have used it to remove freckles.

Another medicinal use has been in dissolving the membranes commonly formed in diphtheria. There is a patented pharmaceutical which utilizes the action of the enzymes on pollen proteins in a nasal spray for relief from certain allergies. Some of the recently prominent protein hydrolyzates are prepared with papain. Papain preparations have also been used in the treatment of peritoneal adhesions following abdominal surgery. The persistent action of papain is of special merit here. Various other medicinal uses are in the treatment of carbuncles, in dissolving the eschar of burns, in chronic purulent otitis media, and to loosen the exudate formed in membranous tracheobronchitis.

The U. S. Dispensatory offers the following additional information regarding the utilization of this exudate:

"Much of the papain imported into this country is used in preparations for rapidly tenderizing meats. The enzyme, being relatively resistant to heat, may be smeared on or mixed with the meat just before cooking. In the brewing industry papain is used for making 'chill-proof' beer, the proteins which would otherwise precipitate on cooling being digested by the enzyme; it is estimated that 80% of American beer is thus treated. Papain is used in the tanning industry for bating skins and hides; and the latex is used in chewing gum manufacture. The fruit of papaya has considerable popularity as an article of food in regions where it is available; its juice is canned and sold in many stores in the United States".

Utilization Abstracts

Lespedeza Oil. Lespedeza has become one of the major crops in the southern States, and in 1948 North Carolina alone produced 36 million pounds of the seed. The latter contain a highly unsaturated semi-drying oil, the potential utility of which is now being investigated. (R. H. Wiley and A. W. Cagle, *Jour. Am. Oil Chem. Soc. 27: 34. 1950*).

Food from Algae. The alga *Chlorella pyrenoidosa* is being grown on a large pilot plant scale at Stanford Research Institute, Stanford, Cal., in an effort to determine whether this single-celled alga, high in protein, can be commercially grown as a source of human food. Soybeans, the highest-protein field crop, can produce only 336 pounds of protein per acre through its inefficient use of only about 0.3% of available solar radiation, whereas *Chlorella*, using over 2%, can produce 44,000 pounds of protein per acre, or perhaps double this amount. (*Chem. Ind. 66: 181. 1950*).

Rice Bran Oil. "Relatively minor amounts of rice bran oil have been marketed in the United States over a period of years. . . . There are no established uses for this oil and it has been employed for such diverse purposes as food and soap stock and as an emulsifier for asphalts". It has potential value, however, as a cooking oil, a winterized oil and a hydrogenated fat. (R. O. Feuge and P. B. V. Reddi, *Jour. Am. Oil Chem. Soc. 26: 349. 1949*).

Cashew Oil. The Irvington Varnish and Insulator Co., of Irvington, N. J., is now furnishing hydrogenated cashew nut shell liquid, a low-melting waxy solid, to anyone who wants it. (*Chem. Eng. 57(1): 161. 1950*).

Pine Tannin. A natural phlobatannin has been extracted from the inner bark of slash pine, *Pinus caribaea*. (F. W. Bope and O. Griswald, *Jour. Am. Pharm. Assoc., Sci. Ed. 38: 192. 1949*).

BOOK REVIEWS

Vegetable Gums and Resins. F. N. Howes. 210 pages. Chronica Botanica Co. Waltham, Mass. 1949. $5.

A very welcome volume has been added to the literature of economic botany by the appearance of this one on the gums and resins of the vegetable kingdom. Mantell's recently published work on the same topics covers their technology and chemistry, and this latest contribution is a valuable companion volume, emphasizing the history, biology, geographic and botanical sources, and other aspects of these plant products.

Dr. Howes' book is divided into two parts, the first treating gums, the second resins, and each part begins with discussions of the chemical and physical properties, the general botanical and geographical sources, and the uses of the exudations. Then follow individual accounts of specific gums or resins, and in these major parts of the volume at least 100 gums and 50 resins are more or less extensively discussed as their importance in trade merits attention.

Gums and resins are exudations of many kinds of trees and shrubs in many parts of the world, thousands of species producing them, but only relatively few in commercial quantities. They are obtained by scraping the hardened and natural or artificially induced exudations from the trunks and branches of the plants that produce them. While the terms are carelessly used interchangeably, " a simple, if incomplete, distinction between gums and resins is that the true gums are more or less soluble in water or swell to a jelly-like mass but remain insoluble in organic solvents, whereas the resins are unaffected by water, but are more or less soluble in various organic solvents. . . . Some plant exudations consist, in the natural state, of a mixture of both gum and resin and are styled gum-resins. The term oleo-resin is used for those resins—of a more or less soft consistency—that occur mixed with a relatively large amount of essential oil. Some resinous plant exudations, particularly those that are medicinal, consist of mixtures of resin, gum and oil, and may be termed oleo-gum-resins ".

" The world trade in natural resins has been estimated to be in excess of three quarters of a million tons per annum ". One group of them, known as "copals ", is obtained from a variety of trees in West Africa, the Belgian Congo, East Africa, South America, the East Indies and the Philippines. The most important of these is Congo copal, derived mainly, if not entirely, from *Copaifera demeusei*, a tall common forest tree of the Congo basin. This same species is the principal source also in West Africa but is replaced by *Trachylobium verrucosum* in East Africa. East India or Manila copal is derived only from *Agathis alba*. Another group of resins constitutes the so-called damars, yielded by various trees of the dipterocarp family in the East Indies, Malaya, Siam, India, Burma and Ceylon. Kauri resin comes from *Agathis alba* in New Zealand, and elemi from *Canarium luzonicum* in the Philippines. These and numerous other resins from a great variety of sources enter into world trade and into many industries, particularly that of varnishes, paints and lacquers.

Gums have similar uses. Most important among them is gum arabic, collected in the Anglo-Egyptian Sudan and West Africa almost entirely from *Acacia senegal*. For many years the annual export from the Sudan alone has exceeded 20,000 tons. Gum tragacanth from various species of *Astragalus* in western Asia is also important, and others, too numerous even to be only mentioned here, contribute to the world's supply of these highly complex products of plant life that enter into the manufacture of an amazing variety of commodities.

The gums have already been discussed at considerable length in this journal by Dr. Mantell (**3**: 1–31. 1949), and a companion article by him on the so-called " hard resins " will appear in the next issue, to be followed in a later issue by treatment of some lesser known resins by Dr. Howes.

The Essential Oils. Vol. 1 (427 pages): History—Origin in Plants—Production—Analysis. Vol. 2 (852 pages): The Constituents of Essential Oils. Vol. 3 (777 pages): Individual Essential Oils of the

Plant Families Rutaceae and Labiatae. Ernest Guenther. D. Van Nostrand Co.

In 1948 the first of this truly monumental work was published, followed in 1949 by the second and third volumes; one or more additional volumes are in preparation; and when all of them have been completed they will constitute one of the most definitive studies that will have been assembled on any group of important products derived from the plant kingdom. The author, Dr. Ernest Guenther, is Vice-President and Technical Director of Fritzsche Bros., Inc., one of the foremost dealers in essential oils, and these volumes obviously represent a crowning lifework of this author, assisted in only a few chapters by contributing writers.

Volume 1 deals with the history, general chemistry, biological origin and functions of essential oils, as well as with methods of production and analysis. The first three chapters are of interest to readers of this periodical, for they are concerned with the origin and development of the essential oil industry; the chemistry, origin and function of essential oils in plant life; and with the methods of distillation, enfleurage, maceration and extraction with volatile solvents. The appendix contains a list of industries and their products, into the manufacture of which essential oils enter. Technological details occupy the remainder of the volume.

Volume 2 is essentially a chemical treatise on the constituents of essential oils, with mention of their botanical sources and industrial uses.

Volume 3 and those to follow are of the most interest to botanical readers, for they "will consist of monographs on individual oils, describing their botanical and geographical origin, methods of cultivation of the plants from which they are derived, techniques of distillation and yield of oil, their physicochemical properties, chemical composition, total production, and uses in the industry". The third volume is devoted to these considerations regarding only two plant families—Rutaceae and Labiatae—for they contain and yield a greater variety of commercially important essential oils than any other comparable group of plants.

These volumes contain a few illustrations, and it is most unfortunate that a scholarly work of this type should be marred, as it is, by extremely poor quality in the reproduction of those photographs. Fortunately this defect is unimportant and does little if anything to detract from a great contribution to the literature of economically important plant products.

Textile Fiber Atlas. Werner von Bergen and Walter Krauss. Textile Book Publishers, Inc., New York. Rev. Ed., 1949. $4.50.

This slightly revised edition of a photomicrographic atlas with text on important textile fibers of animal, plant and mineral origin includes, so far as vegetable fibers are concerned, those of cotton (*Gossypium*), kapok (*Ceiba* sp.), pulu (*Cibotium*), flax (*Linum usitatissimum*), hemp (*Cannabis sativa*), jute (*Corchorus capsularis*), ramie (*Boehmeria nivea*), sisal (*Agave sisalana*), Manila (*Musa textilis*), New Zealand flax (*Phormium tenax*), piassava (*Attalea funifera*), raphia (*Raphia ruffia*), coir (*Cocos nucifera*) and Spanish moss (*Tillandsia* (*Dendropogon*) *usneoides*). There are also accounts of rayon and of protein fibers. Rayon is defined as "filaments made from various solutions of modified cellulose by pressing or drawing the cellulose solution through an orifice and solidifying it in the form of a filament". Protein fibers are made by similar treatment of proteins in milk (casein), soya bean, corn (zein) and silk (fibroin). Also considered in this atlas is alginate fiber, made from alginic acid of kelp. "Both the sodium and calcium salts of this acid have been found to be suitable raw materials for the production of fibers but, up to the present time, the calcium alginate has been of the greater commercial value. It is readily produced by extrusion of sodium alginate solution into a weakly acid solution of calcium chloride containing emulsified oil".

Rayon. Joseph Leeming. Chemical Publishing Co., Inc. 203 pages; illustrated. 1950.

More than two billion pounds of the industrial fiber, rayon, are manufactured annually in various parts of the world by dissolving the cellulose of cotton linters or of certain wood pulps in several kinds of solvents and then solidifying the solution into fiber. Cotton linters are the short fibers that remain on cotton seeds after the longer spinnable

fibers have been removed in the ginning process, and the principal trees that provide the wood pulp for the same purpose are spruce, Southern pine and hemlock. The history and techniques of this very important industrial conversion of a raw material obtained from plants are popularly described in this volume along with discussions of the fabrics made from rayon, their uses and world production.

Citrus Products. J. B. S. Braverman. Interscience Publishers, Inc. 424 pages. 1949. $9.

After first discussing the history, botany, cultivation, marketing and diseases of citrus fruits, the two principal parts of this volume, namely, those dealing with chemical composition and chemical technology, are so extensive as to permit here only a listing of the products obtained from citrus fruits and a few comments concerning them.

These commercially important products are citric acid, pectin and essential oils. In addition, of course, there are jams, jellies, juices and marmalades prepared from the fruits, as well as canned "hearts".

"All citrus varieties contain, to a greater or less extent, organic acids, particularly citric acid. However, only fruits of high acid content, such as lemons, limes, and bergamots, are used in the manufacture of citric acid. The acid is usually made from inferior fruit which is unfit for the preparation of juice to be used in beverages".

"In Italy lemons have mainly been used for making citric acid for a long time; also, the pulp of bergamots has been utilized to a smaller extent. In the West Indies only limes, which are generally somewhat more acid than the lemons, are used".

"The principle on which the present process of manufacture is based is that . . . the citric acid is precipitated from the expressed juice by milk of lime in the form of calcium citrate, which is then treated back by H_2SO_4 and reconverted into citric acid. . . . Before World War I, Italy was the chief producer of citrate of lime, supplying 90% of the world's requirements. During that war and immediately afterward a new method of producing citric acid by fermenting sugar-containing materials was commercially developed in many European countries and in the United States". This fermentation is carried out with certain strains of the fungus *Aspergillus niger* and has been described, along with the production of other acids by fungi, in Economic Botany **3:** 145–157. 1948. A method has also been devised for producing lactic acid from citrus surpluses through the fermenting activities of a lactic acid bacterium.

Citrus fruits are second only to apples as commercial sources of pectin, the most suitable for this purpose being grapefruit, pomelo and lemon. Pectin is concentrated in the peels of these fruits and is extracted in a variety of ways. Its main use is in jam-making, but other outlets are constantly increasing. "Pectin serves as an excellent emulsifier for various oils in water: for instance, for essential oils in flavoring extracts, for castor oil and mineral oil (liquid petrolatum) in medicinal use, and for tree-spray emulsions. Pectin as an emulsifying agent has been compared with gums of tragacanth, karaya, and acacia, and has been found to be slightly better for cottonseed oil and equal to the above for olive oil. As an emulsifying agent for mineral oil, pectin has been shown to be clearly superior to other emulsifying agents. Pectin is extensively used in modern food industry for a variety of confections, salad dressings, and for ice creams. Glue and mucilages are often also made of pectin. Viscous citrus pectin and pectates have recently been shown to be excellent creaming agents for rubber latex, as well as for hardening steel. Finally, pectin has been found to be a good blood agglutinant and is used in the treatment of intestinal hemorrhages".

Appreciable amounts of glucosides, some of them of considerable commercial importance, are also contained in citrus peels. One of them is narangin.

The oils obtained from citrus fruits may be divided into those derived from the peel and those derived from the flowers, leaves and twigs. In the former are the following:

OIL OF LEMON (*Citrus medica* subsp. *limonum*). "Probably the most important and most extensively consumed of all citrus oils. . . . It is produced mainly in Italy and other Mediterranean countries (Palestine, Spain, Portugal and southern France), also in the United States (California, Florida and Texas)".

OIL OF ORANGE (*Citrus aurantium* subsp. *sinensis*). "For a long time the principal source of production was Italy (Sicily and Calabria); later, production started also in the West Indies and the United States (California). Several years before World War II new sources of supply were opened, namely, Palestine, Spain, Brazil, Rhodesia, South Africa, and French Guinea (French West Africa). The production in the last named country has increased to enormous proportions never before attained even by Italian producers; the oranges in French Guinea grow wild and the oil is hand pressed by convicts. The orange oil from this source, however, is of inferior quality. . . . The bitter variety of orange oil is made from *Citrus bigaradia*, and differs but slightly from the sweet orange oil".

BERGAMOT OIL. "This important oil is produced from the bergamot tree, *Citrus aurantium* subsp. *bergamia*, which grows almost exclusively in Calabria (Italy), its fruit being used for oil production only . . . used only in perfumery", not as flavoring.

OIL OF LIMES. Produced in the West Indies from the rind of the fruit of *Citrus medica* var. *acida*. "An oil similar in composition to bergamot oil is also produced in south Italy from the sweet variety of *Citrus limetta*. . . . Increasing quantities of lime oil from a variety called the Persian lime (*Citrus aurantifolia*) which is about twice the size of the West Indian variety, are now produced in southern Florida".

GRAPEFRUIT OIL. "Expressed or distilled from the peel of grapefruit or shaddock, *Citrus decumana*. It is of only recent development and is produced to a limited extent in the United States, Palestine, Union of South Africa, and Spain".

OIL OF MANDARINS. From the peel of mandarin or tangerines, *Citrus madurensis*, mainly in Italy, to a limited extent in Brazil.

OIL OF CITRONS. From the rind of the citron fruit, *Citrus medica* var. *vulgaris* and var. *gibocarpa*.

Oils derived from flowers, leaves and twigs are:

OIL OF NEROLI. "The true oil of neroli is obtained by steam distillation of the blossoms of the bitter or Seville orange, *Citrus bigaradia* (*C. aurantium* L. subsp. *amara* L.). However, more or less successful attempts have been made to obtain a similar oil from the flowers of other varieties of *Citrus*. The production of neroli oil is principally confined to southern France, where the blossoms are carefully picked by hand. Upon distillation some 0.09% to 0.15% can be obtained, about a third of the oil remaining in the water from which the oil is separated in the receiver. This orange-flower water (Aqua Florum Aurantii, Aqua Naphae) is sold as such in perfumery. Distillation of neroli oil has been practiced to some extent also in Spain, Italy, Venezuela, Paraguay, Algeria and Syria".

OIL OF PETITGRAIN. "The name petitgrain proper is given to the oil obtained by steam distillation from the twigs and leaves of the bitter orange, *Citrus bigaradia*. However, similar oils are occasionally distilled from the leaves or twigs (or both) of other citrus varieties. Originaliy petitgrain was produced principally in the south of France by distilling the residues left after pruning the trees; later it was introduced into Paraguay, where the bitter orange grows wild. The Paraguayan plantations were so abused, however, that the vast orange forests have practically been annihilated. . . . It is largely used in perfumery".

Chemical Activities of Fungi. Jackson W. Foster. xviii + 648 pages. Academic Press, Inc. $6. 1949.

This volume, devoted primarily, in keeping with its title, to the chemistry of fungi, contains some references to the industrial production and utilization of those fungal products which have so far found economic applications. Principal among them, of course, is penicillin, the significance of which is so well known that further consideration will not be given to it here except to note that penicillin and other antibiotics today far outshadow in importance all other products derivable from fungi.

Those other products include hydrolytic enzymes, vitamins and organic acids. Production of proteolytic, diastatic and pectic enzymes is well established, and organic acids produced commercially by fungi include gluconic, citric, fumaric, gallic and, potentially, itaconic acid. There are other known prod-

ucts of fungal metabolism, but industrial uses for them have not yet been found and their development awaits the finding of such uses. These include kojic acid, d-lactic acid and itaconic acid. Vitamins, too, come in for consideration, and already riboflavin, pure and crude, is manufactured on a huge scale today by use of the fungus *Eremothecium ashbyii*.

"Molds have proved their value in other ways. Biotin, probably the most elusive of all the water-soluble vitamins in respect to its concentrations in natural materials, for years resisted isolation in sufficient quantities to permit study of its chemical structure until it was found to accumulate in relatively high concentrations during the production of fumaric acid by *Rhizopus nigricans*. A further recent interesting example of this type is the report that antibacillin, a naturally occurring inhibitor for the antibiotic substance bacillin, is found to exist most abundantly in the waste mycelium of *Penicillium chrysogenum* obtained in commercial penicillin production".

"These examples provide the justification for, and are intended to stress a principle that in the future might very well be the guide to more rapid exploitation of, and success in, the isolation of new growth factors of general biological significance. Once a substance is demonstrated to be of widespread use there is reason to believe that through a systematic microbiological study utilizing all the approaches previously summarized, a mold can be found and proper conditions defined, which will result in cultures far richer in the active substance than the usual biological source materials like liver, yeast, milk, cereals, etc. Often the impurities are fewer and more varied, facilitating the preparation of crude concentrates and subsequent isolation in pure form. Most molds can develop on glucose-salts media, thus eliminating impurities contributed by complex organic nitrogenous ingredients. The future of new growth factors must, indeed, look to the molds".

"What new types of compounds in mold cultures will prove to be of value next, only time can tell. Molds synthesize protein from molasses and inorganic nitrogen sources, and possibly may be of value in the preparation of certain amino acids or even in the manufacture of protein hydrolysates. The same holds for fat production by molds. Another prospect not too remote to contemplate, is the production by means of molds of substances having pharmacological action in the animal and human body. These might prove to be safer and more effective than drugs presently available for certain pharmacological effects such as heart stimulants, blood pressure regulators, respiration effects, pyrogenic reactions, metabolism stimulation, etc. Ergot production by the smut fungus *Claviceps purpurea* is a good example of a pharmaceutical produced by a fungus. Evidence already exists for the elicitation of various pharmacological effects by products of mold metabolism. Some of the so-called toxic antibiotics are in this class".

"In agriculture, and particularly in certain specialized phases such as greenhouse, nursery and general horticultural practices, there is a real indication that antibiotic pretreatment of seeds affords protection against plant pathogens, particularly fungi in damping-off diseases, which cause a high mortality in seedlings. General agricultural use of antibiotics would not be excluded on a cost basis if the antibiotic could be used in crude form, as for example, the spray-dried product of the whole culture medium without any purification. The control of obnoxious fungi in still another respect, is a distinct possibility. Mildewing and rotting of textiles is a major problem of the textile industry. Particularly is this true under the warm and moist conditions of the tropics, as experience in the war brought home forcibly".

"All the above-mentioned applications of antibiotics refer to their use in the exact chemical form in which they are produced. Untold possibilities lie ahead for altering the chemical structures of known antibiotics, and for the preparation of derivatives to endow special desired properties on these substances. Thus, the ultimate production may turn out to be a joint process—first, the biological synthesis of the metabolic product; second, its use by the synthetic chemist for further modification. The fertile possibilities implicit here have ample substantiation from the spectacular progress made in the sulfonamides, synthetic antivitamins, and other biochemical substances. Actually this has already been achieved with some antibiotics. The potency of penicillin has been materially enhanced by the introduction of

substituent groups in the penicillin molecule. The very fact that different types of penicillins having different antibacterial potencies are produced by fungi shows the validity of the hypothesis. The most striking example of this type of approach is the reduction in toxicity of gramicidin to one-quarter of its original toxicity, without a corresponding reduction in antibacterial potency, by reacting the gramicidin with formaldehyde. Also, the very low water-solubility of gramicidin was previously a disadvantage, and the modified gramicidin has a substantially greater solubility ".

" Finally, returning to the therapeutic uses of antibiotics, one cannot overlook the possibilities awaiting the discovery of antibiotics effective in a number of infections of man and animals for which no treatment is satisfactory. Thus, protozoan infections, especially malaria, await chemotherapeutic agents superior to quinine and atabrine. Other types of infections, usually associated with tropical climates, such as trypanosomiasis, leischmaniasis, and fungus infections are in a similar situation ".

" The field of viruses is practically untouched in this regard and the promise for antibiotics active against this type of disease agent is limitless. Already information exists pointing to the presence of substances in culture filtrates of certain fungi which destroy the infectivity of yellow fever virus and tobacco mosaic virus. Vast research possibilities are implied here. Quite parallel is the report published in 1943 that impurities in commercial penicillin preparations were effective inhibitors *in vitro* of growing malignant tissue cells, whereas cells from normal tissue were unaffected. The implications for future research and development on this subject are self-evident ".

Mycological production of citric acid " is a huge industry in many countries today, including several European countries, Russia, England, Japan (before the war) and the United States. An institute devoted to the development and improvement of this process exists in Russia. In the United States one company dominates production, furnishing approximately one-half of the 13,000 tons produced annually today. Eighty percent of the total is fermentation citric acid. The rest is contributed by the citrus-fruit industry as a by-product from culled lemons, and a few smaller fermentation companies. In terms of monetary size, the mycological production of citric acid ranks after industrial alcohol (excluding alcoholic beverages), acetone-butanol fermentation, penicillin and streptomycin production, and lactic acid fermentation. The main uses of citric acid are for medicinal products (65 percent) and for foods (flavoring extracts, soft drinks, etc., 14 percent); the remainder is used in candies, inks, silvering, dyeing, calico printing, engraving, etc. All mycological production still is by the shallow pan surface process, although recent patents make it very likely that a shift to the more popular submerged method is imminent within a few years. At least, several companies are directing efforts toward that goal. Naturally, details of the commercial process are trade secrets involving special selected fungus strains, nutrient and environmental conditions, but it can be calculated that the output of the main supplier in the United States must necessitate constant cultivation of fungus mycelium in the range of 10 to 20 acres of surface growth. This, according to one estimation, involves the use of about 37,000 shallow pans measuring 2–3 inches in depth and 3 feet square ". Various strains of *Aspergillus niger* are used in commercial production, and the acid is known to be formed not only by several species of *Aspergillus* and *Penicillium* but also by other genera of fungi.

In recent years itaconic acid has been found valuable in the manufacture of certain plastics, and this acid is now being obtained from cultures of *Aspergillus terreus*. " Itaconic acid fermentation is not yet conducted on full industrial scale, although this is imminent. Production is, however, on such a scale that barrels of itaconic acid are available for pilot plant experimentation regarding various possible applications ".

Gluconic and kojic are two more acids also obtainable from *Aspergillus* and other fungi, but, while there already are industrial outlets for the former, no applications have yet been found for kojic acid.